European Commission

ICT for a Low Carbon Economy

eeBUILDING KEY PERFORMANCE INDICATORS

JANUARY 2014

Proceedings of the
1st Workshop organised by
the EEB Data Models Community
ICT for Sustainable Places

Nice, France, 9th-11th September, 2013

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Acknowledgements

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Foreword

The **1st Workshop on EEBuilding Key Performance Indicators, organised by the**

EEB Data Models Community was hosted at the ICT for Sustainable Places Conference, September 9-11, 2013, Nice, France.

Buildings are responsible for 40% of the EU's energy consumption and 36% of its CO2 emissions. Energy efficiency of buildings is key to achieving the EU Climate & Energy objectives, such as fighting climate change and improving energy security, while also creating job opportunities, particularly in the building sector. It contributes to achieve the EU's concrete targets of a 20% reduction in the greenhouse gas emissions and an increase in energy efficiency of 20% by 2020. The recently adopted "Energy Efficiency Plan 2011" reemphasizes that the greatest energy saving potential in the EU lies in buildings. The plan focuses on instruments to trigger the renovation process in public and private buildings and to improve the energy performance of the appliances used in them. It promotes the exemplary role of the public sector, proposing to accelerate the refurbishment rate of public buildings through a binding target and to introduce energy efficiency criteria in public spending. It also stresses the role new technologies can play in empowering consumers to make choices and behave in a more energy efficient manner.

The European Commission has recognised the potential role ICTs can play in improving the energy performance of buildings in several high-level policy documents. After having set out what ICT can potentially do to improve the energy performance of buildings (see the report "ICT for a Low Carbon Economy - Smart Buildings", European Commission Publication - July 2009), the 2010 Communication "A Digital Agenda for Europe"[1] emphasises that the ICT sector can deliver simulation, modelling, analysis, monitoring and visualisation tools to improve both the design and and operation of buildings

In order to better assess the energy savings potential of ICT solutions in buildings the European Commission has recognised that a more harmonised way of measuring the energy savings in residential buildings and non-residential spaces would be helpful in order to come to a more meaningful quantification.

CIP program pilot projects in social housing and public buildings

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[1] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A Digital Agenda for Europe

In order to support the energy efficiency measurement policies, projects have been funded through the Competitiveness and Innovation ICT Policy Support Programme:

3e-Houses, E3SoHo, eSESH - implement ICT solutions in social housing across Europe and other projects are have rolled-out ICT solutions in and around public non-residential buildings.

- A first version of this methodology was finalised in the summer of 2010[2]
- A second version was delivered at September 2011[3]

The key questions addressed by the event were the evidence of impact of the projects' results. One of the impact KPIs is the net savings that can be demonstrated. The conclusions identified as a barrier the lack of commonly accepted metrics.

This **1st Workshop on EEBuilding Key Performance Indicators**, taking some results coming from FP7 Projects, paves the way for a more intense activity around Energy Efficiency Metrics to happen in the context of the new Framework Programme for Research and Innovation, Horizon 2020, which, amongst other actions, has launched calls for proposals on developing common procedures to collect, collate and analyse energy consumption and missions data to improve the measurability, transparency, social acceptability, planning and visibility of energy use and its environmental impacts.

Ackownledgements: We thank the FP7 European project "Resilient" for the hosting. We thank the Centre Scientifique et Technique du Bâtiment, and to Régis Decorme in particular, for the excellent organisation of the workshop within the event. Thanks to all the projects that have contributed with their high quality papers.

Rogelio SEGOVIA

European Commission

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[2] http://www.3ehouses.eu/sites/default/files/3e-HOUSES_Deliv_1-2_Definition_of_Methodologies.pdf

[3] http://esesh.eu/fileadmin/eSESH/download/documents/outputs/CIP_Common_deliverable_eSESH.pdf

About the IDEAS project

The **1st Workshop on EEBuilding Key Performance Indicators** was organised by the IDEAS project.

The main focus of IDEAS is developing and testing the technologies and business models required to support financially and socially viable energy positive neighbourhoods. Key components of the technologies and business models will be tested at two pilot sites. The project will also explore the possibilities for the incremental rollout of energy positive neighbourhoods across the EU.

The IDEAS project aims to develop and validate the tools and business models required for the cost effective and incremental implementation of energy positive neighbourhoods. These include:

- A Neighbourhood energy management tool: to optimise energy production and consumption;
- User interfaces: to engage communities and individuals in the operation of energy positive neighbourhoods;
- A Decision support urban planning tool: to optimise the planning of neighbourhood energy infrastructures;
- Business models: to underpin the operation of energy positive neighbourhoods that engage end users, public authorities and utility companies.

The neighbourhood energy management tool will enable intelligent energy trading and operation of equipment and buildings along with local energy generation and storage. It will consist of:

- an internet-based infrastructure to manage real-time information flows;
- an optimisation and decision support system for the management of energy production and consumption and energy trading;
- data management and storage services.

The business models and tools will support local energy infrastructures that optimise energy supply and demand, while exploiting wholesale energy markets and local renewables, in ways which make real business sense.

The concept underpinning the business and technical approach is that energy is drawn from national grids only when there is an imbalance in neighbourhood energy supply and demand; or importantly, when it is more economically viable to buy or sell energy from/to the national grid. With the right pricing structure for renewable energy, as a neighbourhood becomes more energy positive it will rely less and less on national energy resources. On reaching energy positivity the surplus energy produced by an energy positive neighbourhood will be a source of revenue profit from intelligent energy trading with national grids.

Energy positivity will become a realistic business goal, for utility companies and public authorities, as tools under development will support a joined up approach to the development and operation of local energy systems. The energy management tool will optimise the current energy supply and demand in real time. The urban planning tool will both improve the efficiency of future urban developments to reduce overall energy demand and help in planning increases to the local supply of renewable energy.

The key performance indicators and data models applied in the IDEAS project seek to build on existing standards, the advances made in earlier EEB projects and learn from the approaches adopted in its sister projects: URB-Grade, EPIC-HUB, EEPOS, ODYSSEUS, ORIGIN, SMARTKYE, E+, COOPERATE and NRG4Cast. All of these projects, like IDEAS, are co-funded by the European Commission under the FP7 program.

As such the requirements for establishing, implementing, maintaining and improving energy management systems in and between buildings in IDEAS will be provided according to international standards (including ISO/FDIS 50001 on Energy Managements Systems, IEC 61850 on Communication Networks and Systems in Substations and IEEE 1547.3 on Monitoring, Information Exchange, and Control of Distributed Resources Interconnected within Electric Power Systems). The lessons learned from the ICT Policy Support Programme (PSP) methodology, used in energy saving management, will also be taken into account.

The eeMeasure methodology for the measurement of energy savings and emission reduction contains information from three previous EU ICT PSP projects: (i) 3e-HOUSES: Energy Efficient e-HOUSES; (ii) E3SOHO: Energy Efficiency in European Social Housing and (iii) eSESH: Saving Energy in Social Housing with ICT. It is based on the International

Performance Measurement and Verification Protocol (IPMVP) standard for energy saving measurement.

The eeMeasure methodology is targeted towards the residential sector where energy use is generally much less, and more difficult to predict, than in the industrial sector. It estimates the amount of CO2 emissions, principally from savings in heat and electricity consumption, that may be avoided by carrying out an energy saving intervention. However there are limitations to the accuracy of these assessments as parameters such as demand response are not fully taken into account in the underlying IPMVP. IDEAS seeks to address this issue as part of its on-going program of research.

Two demonstration sites in France and Finland will be used to validate key elements of the tools, business models developed in the IDEAS project with different business stakeholders and building typologies.

IDEAS website: www.ideasproject.eu

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1. Visualising the 'Big Picture': Key Performance Indicators and sustainable urban design

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Abstract

This paper explores the scope of key performance indicators [KPIs] used in urban development plans and international, national and local government policies and initiatives. The key focus of the paper is how KPIs may be used to support the delivery of carbon reduction initiatives and urban planning projects.

The work presented sets out the scope of sustainability KPIs used during the different procedural stages of a project brief. As such it illustrates how KPIs are used to assess the viability of a project's 'business case' and how KPIs can be used to inform the delivery and on-going monitoring and evaluation of a project.

More significantly, the paper also describes the connections between KPIs at different operational scales of statutory regulation. Drawing from a series of European case studies, it examines policy indicators used within the statutory urban planning and building regulation processes and how these are represented and modelled within currently available ICT decision-support tools. It is suggested that current practice in the use of urban indicators is largely scale dependent and reflects limited, or professionally-defined, remits that restrict the benefits similar KPIs can have over the course of a 'live project' from concept to completion.

The case studies describe scenarios made up of a series of measures which seek to optimise individual project stages rather than work holistically. They highlight some of the unintended consequences of approaches that inadvertently isolate and optimise individual stages of the urban development process. The paper concludes that there is potential to

work more systemically and holistically, using existing data sources more effectively across different procedural actions and at different policy scales.

Keywords: sustainability, key performance indicators [KPIs] and urban development plans

The Scale of Sustainability

Over recent years there have been numerous initiatives and guides offering practical advice in the use of data for supporting sustainable communities, guiding new forms of urban design and adapting the existing urban structure. There has been advocacy for the use of urban models in the design of sustainable cities and layering information on a comparative spatial basis. There is a subtle underlying theme in this body of work about the use of appropriate data that could link, and integrate, some of the thinking at the different scales and levels of strategic urban design interventions. The effective integration of different physical and socio-economic systems is central to thinking about sustainability, however real-world decision making also relates to issues of the scale and the different project stages at which decisions are made. It is also dependent upon the remit of the stakeholder making decisions. In this practical context, sustainability and integration becomes more of a procedural concern than an imposed, substantive solution. As such, the use of meaningful data, indicators and measures has a critical role in this process. Thus, the current stakeholder or 'practitioner' focus in the development and use of key performance indicators [KPIs] is around indicators used as procedural tools to support local and project decision-making.

> "Close examination of recent housing … standards … indicates a tendency to adopt a piecemeal approach that relies on outdated data sources and references … [a] process of cobbling together existing standards" (Milner & Madigan 2004 p.739).

Integration around sustainability and quality indicators requires more than simply patching together separate topics that measure one of the elements of sustainability. Integration also has to occur with regard to both the scale and scope of interventions.

Coordination and consistency between scales of intervention from the macro (city and region) to the micro (buildings and components) is a prerequisite of sustainable design. While it has been recognised that in practice, most work is undertaken at a multi-layer approach, seeking to integrate work at different scales of operation (Carmona 2001), achieving this integration is not a straightforward task.

European and national governments and agencies have taken steps towards integration by setting, and then mandating, standards. They have attempted to lead by example (for instance, in establishing integrated standards for land disposal and funding eligibility, English Partnerships 2006) in the piloting, measurement and testing of standards. There have been studies looking at potential conflicts with localised requirements and site practicalities. There have been attempts to extend and develop many findings from pilot sustainability and low-energy projects. For example, the UK 'Carbon Challenge competition' sites included zero carbon homes plus sustainable considerations at each stage of the design and construction process from participation, planning, detail, lean construction and on-going neighbourhood management to "…. incorporate lifestyle features and designs for behavioural change so that residents may live low carbon lifestyles … (and) … demonstrate how such homes can be produced for the wider market"(CLG and English Partnerships 2007).

However, beyond the government supported exemplar projects and initiatives, the main mechanism proposed for integrating the different physical and technical systems for sustainable performance in the UK is the Code for Sustainable Homes (CSH) (CLG 2005, CLG 2010). This has a focus on individual properties and technical solutions with some limited potential for rescaling.

Property Scale KPIs - The 'Code for Sustainable Homes'

KPIs are extensively used as part of the accredited approach to assessment at the project design and post-completion stages. Within the CSH there is a combination of 'essential' and 'desirable' measures, each providing a score towards the overall standard. The 'desirable' elements are those left to the decisions of the design team to allow trade-offs between issues such as potable water use, site ecology and construction management processes. The 'essential' elements on energy and carbon dioxide emissions have implicit KPIs requirements that relate to *DER (dwelling emission rate)* and *TER (target emission rate)* figures. These are measurements commonly used to calculate the *FEE (fabric energy efficiency)* within the UK's SAP (standard assessment procedure).

This cross referencing to existing KPIs described within statutory requirements, such as building regulations, does have the effect of common language and reference points for comparison and evaluation. At a localised scale, many planning authorities are now refining their own sustainability standards in the context of a *percentage improvement over the TER*. As such they are using the same KPI measurements and methods and sign-posting stakeholders towards CSH as one of the most appropriate sources for specification guidance.

With the exception of a limited number of urban scale KPIs, such as site density (*gross number of dwellings per hectare*) and development mix *(gross floor area by land use)* the CSH limits measurement to the dwelling scale. This is as much to do with the confidence in, and availability of, appropriate data at the neighbourhood scale, as it does with theoretical understandings of sustainable design.

It would seem that sustainability thinking as grounded in the *Code for Sustainable Homes* is still restricted to the dwelling or site rather than the neighbourhood or city scale.

Consequently, the policy emphasis on the integration of technical systems at the scale of the individual building has led to less detail being available for measuring sustainability at the neighbourhood scale.

While there is significant work exploring the idea of typologies for urban neighbourhoods within a climate context (Prasad et al. 2009 and Ewing et al. 2008) and a recurrence of thinking and planning at the scale of the neighbourhood, much of this work is also theoretical and hard to pin down with regard to setting specific objectives, measurements and assessment. For example, certain projects need 'outcome' assessments for their particular investment model that demand measurable social benefits. Igloo (a sustainable & social investment pension fund)"are in the process of improving [their] ability to quantify these, often hard to measure, benefits, in particular those that contribute to societal well-being" (Brown 2012 p.26). It is important to note that these measurements do not have to be based on monetary or technically based KPIs.

There are also significant problems in scaling up technical solutions. For example, one of the most famous attempts at scaling up some of the innovative thinking on sustainable energy and water systems, buildings and lifestyles, Bedzed in Sutton in the UK, had serious operational difficulties (Slavin 2006 p.9). Many of these problems arose from the use of untested technologies at the neighbourhood scale (Slavin 2006 p.9). Perhaps somewhat unsurprisingly the greatest saving in carbon emissions for collective CHP, car clubs and other behavioural issues resulted from the high density form of the Bedzed development and the fact that the development attracted those with a concern for the environment to live there. Yet aspects of ***urban density*** and ***occupant preferences*** are not generally considered as sustainability KPIs.

There are additional concerns over the implications for larger scale densities and mix of land uses on local neighbourhood energy demand and the viability of different technical systems. This means that what seems optimal at the household scale is not necessarily the most appropriate solution at the neighbourhood scale. It is also suggested that there is a real issue about maintaining design quality and identity in the face of overpowering sustainability requirements and that these are as important as costs and construction issues (Elliot 2006).

Project Scale KPIs – New development in 'Copenhagen's North Harbour' and large-scale retrofit in 'Newcastle's Riverside Dean'.

Stakeholder scoping was conducted in three separate case studies. These included a mixed new urban quarter at Copenhagen's North Harbour and the large scale retrofitting of a social housing estate in the West End of Newcastle upon Tyne. This exercise identified a total of 62 separate KPIs (Niwaz *et al* 2012) intended to be generic and transferable to similar situations and project scenarios. These KPIs take the form of energy efficiency and CO_2 emission variables (Gallopín 1997), that are measurable and represent the operation of both neighbourhood and building scale energy systems.

These are overtly technical measurements that are used to calculate the high-level performance indicators. They are used as factors for establishing baseline energy demands (*Energy demand for final energy uses, Demand for different energy carriers, Energy distribution losses*), the proportion of this demand met by renewable sources (*Energy carriers from renewable energy sources, Renewable energy in the total electricity supply, Share of local electricity carriers from renewable energy sources, Share of local energy carriers from renewable energy sources*) and the resultant emissions (*CO_2 emissions and reduction compared to baseline*). Calculations including – income, socio economic considerations and energy costs provide indicators that support the evaluation *of energy efficiency options* and the assessment of *fuel poverty*.

These are typical of project-specific KPIs that concentrate on measurable outcomes set within the initial project briefs, be it the development of a zero carbon neighbourhood (North Harbour, Copenhagen) or the area-wide removal of fuel poverty (Riverside Dean, Newcastle).

Urban Scale KPIs - The Covenant of Mayors

This European cooperative movement involves local municipalities making corporate commitments to a target level of a 20% reduction in CO_2 emissions by 2020. These are generally delivered by Sustainable Energy Action Plans (SEAP) that rely on KPIs to measure a *1990 baseline level of CO_2 emissions* and a year on year *percentage reduction*. Actions within the individual SEAPs vary enormously between different cities and locations with each signatory municipality deciding on their own set of indicators and measures.

More localised KPIs generally relate directly to the contents of the SEAP and include *process indicators* around the effective implementation of SEAP activities. They include benchmarks relating to public lighting and facilities, transport, buildings, even behaviour and good manners. The benchmarks used in each individual case reflect the statutory responsibilities and areas of control via purchasing and public private partnerships etc. Therefore the appropriate indicators shown in a meaningful way to provide information for the appropriate stakeholders are important in moving the municipality towards their CO_2 emissions targets.

Integration also relates to KPIs measuring issues of ***occupancy*** and ***behavioural characteristics***. There are a growing number of studies highlighting the interrelationship between social factors such as demographics, levels of occupation and energy consumption (Energy Saving Trust 2012 and Crosbie and Baker 2010). These all show that when consumer concerns, preferences and attitudes are included, in any evaluation, things become more complex: And when consumer and occupancy concerns are scaled up, for example in Britain’s *Green Deal*, so is the complexity and chaos associated with policy interventions.

National Scale KPIs – The 'Green Deal'

Nowhere has the need for an accurate understanding of upfront *capital costs* and *potential energy savings* from retrofitting work been as critical as with Britain's Green Deal (Guertler *et al* 2013). This 'pay to save' business model relies on assessed energy savings from a package of energy efficient works to the fabric and the energy systems of existing properties. KPIs relate to existing *carbon emissions*, *energy demand* (space heating, hot water, electricity) and potential *carbon and energy savings per annum* over a fixed period. It also has a calculated 'Golden Rule' making finance available for those with a *pay-back period* of less than seven years. Here, the process of assessment is particularly important regarding issues of trust in both the accuracy of the costs / predicted savings (Bioregional 2011) and those installing the works on behalf of those responsible for utility bills (not necessarily the property owner). Critical to the scheme in operation is a lack of effective integration between predicted energy savings and finance rates, with the result that "… the government's flagship energy efficiency programme … has become something of a shambles" (Brignall 2013 p.4).

Acknowledging the benefits of integration in its' broadest scope for sustainability, practice is still restricted in attempts at integrated design. Practitioners are still largely limited to the measurement and assessment of technical issues and scared by the complexity of human interactions, preferences, values, tastes and lifestyles when thinking at the scale of the urban designer and town planner.

> "The objective approach focuses on results, not the process by which results are achieved. ... (while) (p)rocess approaches see planning as much more than a technical process" (Marcuse 1976 p.271).

Yet sustainability isn't just about scale. It has procedural elements that incorporate the central idea of 'integrated design'. Thinking about sustainable systems requires different ways of collaborative and interdisciplinary working between professionals, politicians and community stakeholders with local ownership and involvement. It requires the early involvement of key professional skills in areas such as architectural design, energy strategy, materials and specifications, supply chain considerations and long-term management. The supply chain concerns are also significant where the design process has to be based on requirements and understanding of the construction, materials, and the full range of factors impacting on manufacture, assembly, management, repair and adaptation. Yet, there are seldom KPIs used to assess these stages in the project process. In the real world of urban planning both process and outcomes are important areas for measurement and assessment.

'Outcome' versus 'process' indicators

Comparative studies of urban scale KPIs have stressed the need for constant review and evaluation of their use in practice. Their selection requires some degree of consistency suitable for international comparison (Shen *et al* 2010) as well as setting a useful baseline for local level monitoring (Munier 2011). Urban scale KPIs have to be measurable and relevant to urban planning outcomes; in that they reflect local objectives and priorities or processes (Zhang *et al* 2008) and ideally present a simplified view (Mega and Pedersen 1998) of a complex system. While this suggests pragmatism is essential in the use of any set of indicators (due to availability and cost of data, relevance to national and local policies), perhaps the key distinction is between 'process' indicators (measuring the implementation of policies or actions) and 'outcome' indicators (measuring the impact of the urban planning process).

Strategic 'outcome indicators' have been defined by the 'vision' of sustainable regeneration within central government (ODPM 2005) that in itself has been informed by earlier scoping studies (for example; Turok and Kearns 2004, Housing Corporation and European Institute for Urban Affairs 2003). This work suggested a broader range of indictors within a toolkit of measures that reflect similar definitions of sustainable communities. This 'toolkit' approach was applied in the Housing Market Renewal (HMR) programme and found their way into the Egan review (Egan 2004) and became the core of those current indicators within urban planning and regeneration activities within the UK.

Urban Scale KPIs – the 'Housing Market Renewal Pathfinder' Initiative

The Housing Market Renewal Initiative was part of the national framework for urban planning, complementing the (mostly) southern growth areas with managed housing-led regeneration in the (mostly) northern urban conurbations. The aim was to stabilise local housing markets through planned interventions around a mix of demolition, refurbishment and new house building. The range of KPIs reflected this explicit economic bias with some weight given to softer measures relating to community cohesion.

Within this HMR programme, a review of the core performance measures (ECOTEC and Nevin Leather Associates 2009) shows that key performance indicators relate mostly to the targeted delivery of the business plan. They assessed the effective delivery of business plans rather than the actual impact of the business plans on the stability and sustainability of the local housing market. This review also found that business plans were placing the greatest weight on economic measures and noticeably missing any core indicator relating to environmental sustainability and energy efficiency performance. In practice, many of the significant outcome indicators were forgotten and there was a dominance of process indicators, where data was readily available. There were similar reasons in the limited use of locality specific indicators. While local key performance indicators generate diversity they also create a degree of inconsistency in measurement around the country makings comparisons and the development of national indices difficult. There were also often problems with locally self-defining indicators due to the availability of information at a small area basis (Bramley *et al* 2007). Even with the use of supposedly integrated indicators, there were unanticipated consequences, or displacement impacts, within other areas and housing markets that were not being directly recorded in any form of impact indicator (ODPM 2006).

In practice, many of the locality defined indicators relating to energy efficiency and sustainability are based on subtle variations around some of the nationally recognised standards and measures. Indeed this wider perspective of sustainability in urban planning and regeneration (as defined through the set of indicators and measures adopted) has been replaced with a smaller number of transitory indictors based largely on assessment of funding priorities. For example, the numbers of voids / empty properties and *percentage of properties abandoned per street*, HCA 2011. 'Process indicators' also relate to post-completion and occupancy stages. Practice based reviews (LCEA 2011) suggest that KPIs and information should be linked in some way to incentives or 'rewards' for behavioural change and reflect key actions within a behavioural change strategies, for example, *reductions in annual energy bills* and *uptake of energy efficiency improvements*. Most KPIs are derived from policy and their use in practice is either mandated or dependent upon national or local government funding. A condition or requirement of funding is what is generally meant when people talk about 'core indicators'. This is consistent with other areas of grounded-research (Innes & Booher 2000) that suggests there is no generic model or set of indicators for any city or region. They simply have to be fit for purpose regarding scale, cost, and rapid feedback and as such have to be framed with the user involved from the outset.

It also has to be remembered that the choice of KPIs is also a political decision, which sets both a definition of sustainability and an agenda for change (Crilly *et al* 1999). As the emphasis in the use of key performance indicators has moved towards more data-defined indicators; and a bias towards quantitative and economic indicators, the scope and importance of sustainability is diluted.

This perspective sets some interesting requirements and questions for KPIs and the framework from which they are selected.

- With regard to scale, can KPIs be used to assess household energy consumption? Is the data underlying a KPI suitable for aggregation and / or disaggregation and therefore suitable for informing decisions at a variety of different operational scales?
- With regard to stage and processes, is it possible to use the same set of KPIs in a technical brief right through to post-occupancy monitoring of properties and energy systems? Is there even a commonly recognised set of work stages between different professional disciplines working at different stages in any project? Are 'practitioners' limited in the choice of KPIs by their professional discipline?
- With regard to scope, do KPIs allow for comparison between economic costs, social acceptability and technical performance? Are the assumptions of achieving buildings and cities that are sustainable and affordable even achievable? Are we able to recognise the empirical bias of how KPIs are used to guide policy and practice?

- With regard to outcomes, can we make any clear associations between the impact measures and the success of policies if we are only measuring the policy implementation process?

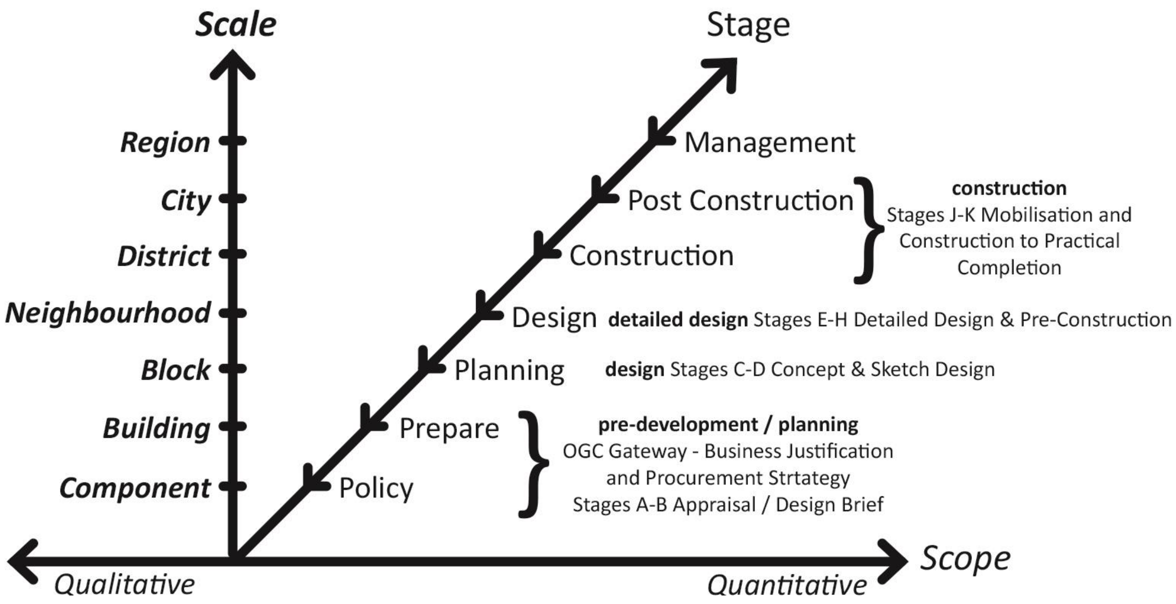

Figure 1. Alternative framework for integrated key performance indicators developed from the Stakeholder Capture Requirements exercise undertaken for the Semanco project.

Our response to these questions has been informed by an exercise in capturing stakeholder (decision-making 'agents' and technical 'users' of evaluation and assessment tools) requirements around the use of KPIs for sustainability and energy efficiency. This framework (figure 1) seeks to address the relationship between three 'dimensions' of sustainable design. Specifically (1) the scope of sustainability (integrating subjective and empirical measures), (2) the scale (detail / operational scale for potential interventions and / or initiatives to address energy efficiency and the reduction of carbon emissions), and (3) the stages of decision-making (related to professional disciplines).

The research underpinning this primarily concerns the identification of a conceptual framework or 'toolkit' of KPIs that are useful in practice to a range of professional disciplines working at different scales and at a variety of project stages. In mapping out the KPIs that are currently used regarding energy efficiency and carbon emissions, we can also begin to highlight gaps in themes, scales and work stages. In short, it can help to maintain a more holistic view – the bigger picture of what is happening.

Integrating Information and Data Modelling

One of the key factors influencing the choice of KPIs is the availability of meaningful and relevant data. In response, this section sets out some ideas for using a 'toolkit' approach to KPIs that begins to integrate actions at different scale and stages of project work and make the best use of available open-source data. The idea behind the integration of data is one of semantic modelling.

> **Integrated KPIs - Semantic Energy Modelling**
>
> The 'Semanco' project sets out to apply Semantic Energy Modelling, to support the calculation of a set of energy based KPIs within the practical context of limited data of the right format and sources. KPIs were defined by the stakeholders through a series of use cases. A summary of the project capture requirements (Crosbie *et al* 2013) highlighted significant implications for the selection and use of KPIs. These implications particularly regarded the appropriate use of metadata standards (e.g. sources, dates, sampling and accuracy) and protocols that provide comparison that require indicators in understandable units of measurement and which are referenced in national, regional or local policies or mandated standards. Here there has to be a recognition of the importance of high-level standards in informing more localised policy and thus the choice of any indicators used for measurement.
> The collection of appropriate supporting data considered the data format (spatial / three-dimensional) and the scale(s) of operation. This generally reflected the operational scale of the key stakeholders working in sustainability and energy efficiency. It considered the source of data, whether it was actual / monitored or modelled data and the cost-effective use of open-source public data. The developing semantic structuring of data is supporting KPIs in a 'toolkit' that is pragmatic around the best use of cost-effective data and sharing data at different scales of operation and stages within any project implementation. The stakeholder is able to self-select and visualise their own specific energy-related indicators using the platform developed as part of the SEMANCO project Madrazo et al (forthcoming).

The idea of semantic information being applied to urban planning and design is not new. Haken and Portugali (2003) suggested an approach based on pattern recognition and building geometry. Another applied example is pattern recognition in the size / density of settlements as part of a self-organising hierarchy (Samet 2013). This proposes some ideas for structuring data in a 'layered' manner that can be used in the formulation and application for suitable KPIs. Indeed, there are increasing numbers of examples of data-rich indicators that go beyond the principles and theory into how spatial data can be used to inform strategies and responses to urban resilience (Pickett *et al* 2013) and sustainability (Crilly and Mannis 2000). More recently, KPI data is being organised in three-dimensional geodatabases (Dalla Costa *et al* 2011) "... including geometry and semantics, later developed in CityGML standard format." (Dalla Costa 2013 p.27). In the same way, things have come a long way towards the semantic modelling of building energy use (Grzybek *et al* 2011) for comparison and testing of options from an initial interest in thermal modelling, lighting, daylight and airflow (Eilers 1999).

Yet in such an approach to the use of KPIs, supported by computer modelling, there are errors and uncertainties associated with any data input. Indeed, there is a suggestion that there is an academic tendency for KPIs to be driven by the data (Ennis and Madrazo 2013). Whether this is due to practical availability or research interest, rather than the stakeholder requirements is unclear. In response, the emphasis in any application is on the consideration and evaluation of different options. This type of evaluation and 'agent-based' modelling (Portugali 2001) has been largely absent from most 'standardised' energy calculations. We have to be honest and say that semantic data doesn't yet support accurate predictive models but that it rather supports explanatory and exploratory models which provide 'ball park' predictions. However this does allow comparisons of the different options for increasing urban sustainability at different analytical scales to inform decision making.

Real World data is noisy

> "Networks are everywhere. It is a structural and organisational model that pervades almost every subject, from genes to power systems, from social communities to transportation routes" (Lima 2011 p. 73).

The implications of maintaining a 'big picture' through the use of a set of KPIs, are to do as much with the underlying conditions of the systems being measured as with any individual indicator or metric. In building up a picture that is holistic and representative of a sustainable system (neighbourhood, city or regional scale) there has to be some reflection of the complexity around the inherent conditions of that system. The system will be complex, unpredictable, self-organising and thus there has to be an understanding and appreciation of uncertainty, errors and risks in the use of any proxy measures in describing the behaviour of this system.

> "Complexity itself can be deceiving. Biogenic complexity constrains entropy flows with checks and balances. What we take to be man-made artificial complexity (technology) is, paradoxically, a simplification process that increases flows by editing away inefficiencies. ... Everything we identify with the man-made substitutes for natural bio-economies, that is, technologies, tend towards positive feedback, which is self-amplifying, self-reinforcing, and destabilizing, featuring the removal of constraints to entropy flows and leading to the certain eventual destruction of that system" (p191, 192, Kunstler 2005).

For example in relation to the assessment of energy and carbon emissions, there are errors relating to the data collection methods (uses of approximations standardised inputs etc.), the accuracy of open-source data (for building geometry, property ages, methods of construction etc.) and the separation from any variable associated with occupants. What is available through specific KPIs is simply an abstraction of reality. It is simplified and standardised. However, they are still the most cost effective way of assessing the potential energy performance of a property/city/region independently from the difficulties of qualitative variables.

In writing about the pitfalls in the use of big data, Silver (2012 p.9) states "(t)he numbers have no way of speaking for themselves. We speak for them. We imbue them with meaning." It is similar when indicators and measures are used in calculations of climate and carbon emissions. They often ignore the importance of errors, and levels of uncertainty as part of making sense of the complex system. As planners and policy makers, we set the semantics for the data. This is why the SEMANCO project has developed front-end tools to facilitate end user involvement in the semantic data modelling underpinning the project and the exploration of semantically modelled data. In this way it ensures the outputs of the project are of value to end users (Madrazo et al Forthcoming).

Conclusions

Dealing with urban sustainability means addressing the procedural aspects and varying scales at which decisions are taken that impact on energy consumption and carbon emissions. Activities and KPIs at the urban design / neighbourhood and city scales need to be aligned with and supported by the regional and national governmental structures and cultures. Experience has shown that without consistency between scales of action there will inevitably be a 'gap' between policy and delivery. This will be the case, even allowing for some level of flexibility and creativity to achieve the important performance indicators at the local level. We need indicators not just to measure processes but as a reminder of the scope and definition of sustainable urbanism.

Addressing sustainability also requires thematic integration. It is clear that there are overlapping and complex relationships between spatial planning, urban regeneration, energy policy and technical standards. Many of the technical details and parameters also have systemic relationships with socio-economic systems. Central to these key associations are the economic implications for renewable energy strategies and issues of affordability (affordable warmth, fuel poverty and fuel security) of properties. In most cases, the significant KPIs are those relating to the 'triple-bottom line' and the need to demonstrate the cost effectiveness of using appropriate sustainable technologies. There has to be benefits on several levels, including the medium to long term cost benefits of management and maintenance. Thus any measurement of impacts and options for achieving carbon reduction without associated costs will not have any real practical application.

Finally we have to maintain the *bigger picture* with regard to urban sustainability. This might mean working outside of our professional restrictions to coordinate between different stakeholders, scales and stages of intervention. It also means being aware of the limitations of our own evidence, as defined by data and KPIs. It means being open to displacement effects and unexpected consequences of some policy interventions. KPIs can help to build a picture of how well things are being done ('process indicators') and the observable changes being effected ('outcome indicators'). However, used blindly KPIs can have unexpected consequences. Therefore even in the world of 'big data', it needs to be understood that KPIs must be used with caution. Planning and managing urban change is complex and contextually contingent. We have to accept that when planning sustainable urban change 'one size' does not fill all. However there is undoubtedly a potential to work more systemically and holistically, using existing data sources more effectively across different procedural actions and at different policy scales.

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2. Key Performance Indicators (KPIs) for Continuous Commissioning

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Abstract

The use of ICT devices, building automatic control system and technical building management, with an appropriate building operation management, can decrease energy consumption from 5% to 30% [**1**]. Only rarely building performance are continuously evaluated in order to verify that the design performance are maintained both in term of energy efficiency and indoor environmental quality (IEQ) or to improve the system operation and set up. As a result, often the real building performance is quite different from how the building was intended to behave. Therefore, the Continuous Commissioning plays a relevant role in the energy assessment to solve operation problems, improve comfort, optimize energy use and identify retrofit strategies for existing buildings and plant facilities. In the current paper, we present a methodological approach of KPI-based continuous commissioning with example application on two case studies (one apartment building and office building). Through the application of this methodology was possible to identify the importance of resident behaviour for the apartment building and of the system regulations for the office case study. Resident education and corrective actions are being undertaken to achieve savings and improve comfort conditions.

1 Introduction

The recurring and persistent request for the reduction of building energy consumption requires an increasingly detailed analysis of the building-plant system performances. Indeed, a detailed continuous monitoring and data post-processing procedure can guarantee that the actual building behaviour respect the design as well as that the realization and operation was successful. Additionally, it can also identify anomalous management of the building systems and habits of the people who occupy the building as well as other possible problems of the plants or façade. The required monitoring system is composed of a series of sensors, meters and other instruments that must be applied for at least one year to acquire data useful to characterize the building energy performances during both heating and cooling [2]. Specifically, the first year of operation of a new building is often used as training for both the occupants to adapt to the new conditions and the building manager to familiarize with the controls and features of the building. Therefore, often the consumption of the second year is reduced compared to the first one if appropriate monitoring-based commissioning is implemented.

The Continuous Commissioning (CC^{SM}) [3] (i.e., the continuous evaluation of measured performance indicators via ICT devices) is based on the development of a standard analysis process which examines the building from its early phase (design) through its realization, to the consequent real usage of the people who occupy it. It is necessary to define the main parameters influencing the energy consumption that must be part of a monitoring plan (based on ICT devices) that also include energy drivers. The data collected through ICT devices can be processed to develop graphs, metrics and summary indicators characterizing building performance. These Key Performance Indicators (KPI) represent a critical point in the commissioning process. With the generation and interpretation of these KPI it is possible to effectively inform both the energy manager and the building owner or inhabitant. A correct comparison between the consumption profiles in different seasons and between different buildings with the same usage purposes and executive typology can be made thank to interpretation tools [4]. With this information, improvements can be suggested after a deep study of the interactions among variables and the identification of the affected systems. Therefore, data post-processing procedures and tools must be developed or adapted to assist with the data interpretation and to understand the connection among the variables as well as to visualize possible plant malfunction[5].

Considering the need for standardized procedures to post-process and analyse data regarding existing building performance, we developed standard KPI (figures and metrics) and applied them to two case studies, one office and one residential building. With these analyses education and corrective measures can be implemented to achieve savings.

2 Methods

In order to develop the standard post-processing procedure, we first evaluate the possible metrics and visualization tools typically used for building performance characterization. The figures and KPI selected should have the characteristics listed in Table 1.

Characteristic	Description
Relevance	Check whether the available information shed light on the issues of greatest importance for the users
Accuracy	The degree of correspondence between the estimates obtained by the analysis and the true value.
Accessibility	It refers to the simplicity for the user to find, acquire and understand the information available in relation to its objectives.
Comparability	It is the ability to compare the statistics on the phenomenon of interest in time and in space. Process information.
Coherency	It corresponds to the possibility of combining the simple inferences in inductions more complex.

Completeness	It is a cross-characteristic between processes and it is the ability to integrate this information to provide a satisfactory framework of the domain of interest.
Regularity	It indicates the frequency with which the analysis is repeated and the data are made available.
Clarity	It is the availability of appropriate documentation in respect to the characteristics and phases of analysis, with the possibility of obtaining assistance in the use and interpretation of data

Table 1. Main characteristics to be considered during data post-processing and the protocol development

Secondly, since the structure and the tools used in the post-processing procedure should be common to the different buildings investigated, a sets of possible visualization types was identified (e.g., figures, diagrams).

Table 2 presents the visualization tools used in the current methodologies with advantages and disadvantages. The performance evaluation would have similar structure and specifically include: electricity (e.g., plug loads, lights), thermal & mechanical plants (HVAC, DHW), IEQ (e.g., hygrothermal comfort, CO_2), user behaviour (window/door opening), RES (e.g., PV) [6].

Type of visualization	Description	Advantages	Disadvantages
Time series plots	Classical diagram of a measured value over time (on the x-axis).	Rapid creation; clear visualization of trend over time, peak values; clear comparison of before-after scenario.	Lack of information regarding the correlation between variables; no summary information about the distribution; depending on data resolution, significant information could be hidden.
Scatter plots	Figure showing a variable as a function of another variable(s).	Clear visualization of the relationship between variables; easier to understand the possible mathematical relationship between variables.	Unless different colours are used, hard to understand the time-dependency and the influence of other aspects; critical to identify the correct variables to compare and for sophisticated analysis the relationship among them.
Box plots	This graph depicts information regarding the distribution (median, lower &	Useful to visualize the statistical distribution of a variable; when coupling with	Lack information regarding the specific values, especially regarding time-dependent

	higher percentile, outliers) for different grouping strategies.	grouping useful to quickly compare distribution for different conditions; the shape of the boxes also helps in identifying the variance and the frequency of outliers.	phenomena and relationship between variables.
Carpet plots	They illustrates the values of a certain variable on a colour scale versus time. Usually they show the hours of a day on the y-axis and the days of a year on the x-axis. Each coloured pixel of the graph indicates a high frequency data point.	Effective to clearly visualize long-time series; effective to show recurring patterns or operation schedule	Lack the information regarding dependency among variables; lack summary indicators, although the frequency of colours can be used as surrogated metric; they may require advance data processing tools.
Tables and visualization bars	They include summary indicators as values possibly supported with colours (visualization bar).	They can provide quick summary information regarding overall and specific behaviours, typically average value; the visualization bar could be easy to quickly grasp.	Provide limited detail information regarding the reason for a certain behaviour and the correlation among variables; challenging to compare the values and define the correct meaning of the colour scale.

Table 2. Visualization tools

To facilitate the analysis and understanding of the data two important tools exist: filtering and grouping [7]. Filtering consists on the selection of a subset of data that satisfies a certain condition, while with grouping all data are considered but grouped according to a specific logic. Important for the data analysis is also the resolution and duration of the data series. Different information can be convened depending on the data resolution (minute, hourly, daily, weekly, etc.). To assist with this process we relied on a commercially available software.

3 Case study application

The developed methodology of KPI based continuous commissioning was applied in two recent ongoing projects: SEE-Miniambiente (2009-2013); ICT PSP Smart Build (2012-2015).

SEE-Miniambiente “CasaNova” apartments

The first project concerns the study of an innovative “CasaNova” neighbourhood in Bolzano, Italy which was built in 2007 according to high energy efficiency standards. The district is composed of 31 buildings, with different shapes and sizes, which are grouped in 8 residential nucleus named “Castle_EA” (i.e., cluster of buildings). Figure 1 shows an aerial view of the neighbourhood.

Figure 1. Overview of the “Casanova” neighbourhood.

The project was realized to fulfil 3 main objectives illustrated below:

1st Objective – Reduction heating consumption

The first objective of the development was to have a low heating consumption. The limits of heating demand set by Italian Standards in 2003, when the project was approved, was 90 kWh/m^2/year. For the CasaNova district, the municipality of Bolzano decided to apply more stringent thermal energy limits, based on the size of each building:

- Buildings smaller than 5,000 m^3 the limit was 50 kWh/m^2/year.
- Buildings larger than 20,000 m^3 the limit was 30 kWh/m^2/year.
- For buildings with volume between 5,000 m^3 and 20,000 m^3 the limit vary according to special classifications, presented in Figure 2**.**.

This strategy attempted to not penalize smaller buildings to the detriment of the bigger ones, which have a lower surface area to volume ratio.

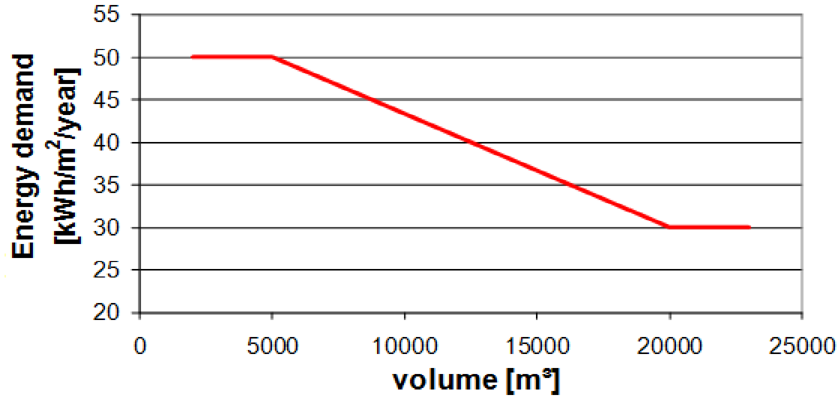

Figure 2. Correlation between energy consumption and Volume of the buildings

2nd Objective – Rational and efficient utilization of traditional energy sources

A preliminary study was done to decrease the energy consumption from traditional energy source. First, different heating configurations were considered: independent boiler for each apartment, a centralized boiler for each building and the use of the district heating network. Subsequently, based on the detailed analysis of the overall average efficiencies of the three configurations, the district heating network was chosen. Additionally, a cooling district plan was implemented via absorption machines.

3rd Objective – Use of renewable sources

Most of buildings in the neighbourhood have renewable energy systems like solar and geothermal. The solar energy is used to produce domestic hot water and electricity. The geothermal plant helps not only the heating and cooling system of the buildings with a water circuit, but also the ventilation system. The aim of these devices was to reduce the energy consumption and guarantee a high indoor comfort. The reduction in simulated consumption as results of these three objectives is illustrated in Figure 3.

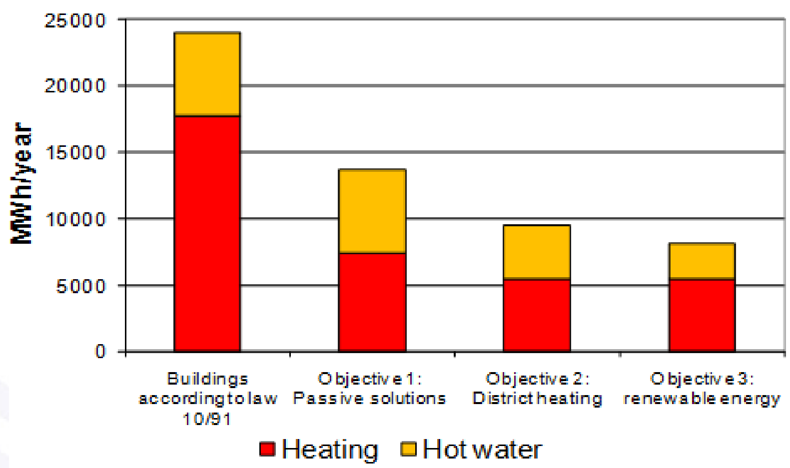

Figure 3. Consumption reduction for Heating and hot water via the application of objectives

According to the province of Bolzano, a detailed monitoring system has been applied in some "castles" since 2009, for example "castle-EA2" (see figure 1). This cluster is made of 4 buildings and each one has different height and sun exposure. The project of this residential nucleus aims at reducing the heating energy consumption with the following prescriptions:

- use of high thermal insulation thickness (from 10 to 15 cm of rock wool).
- glass walls with different size in function of the orientation
- thermal transmission coefficient of the glass equal to 1,1 W/m^2K and 1,4W/m^2K for the frame
- external wall in insulated brick with thickness of 30 cm.
- ventilated façade.

The thermal energy is obtained via the district heating network. The solar collectors located on the roof and three tanks, one of which is connected to the heating system, ensure the production of domestic hot water. An area of 270 m^2 of photovoltaic panels provide part of electricity consumption.

The monitoring system was installed to assess the real energy consumption and verify the IEQ in 4 apartments: two located on the ground floor and two on the last floor. The system is composed of:

- Energy counter for the district heating network
- Electricity analyser to evaluate the consumption of lights and appliances.
- Sensors to measure in the four apartments indoor temperature, moisture, CO_2, opening/closing windows and temperature of external ventilated façade, in both sides.
- Weather station installed on the roof of the building to evaluate the temperature, moisture, global irradiation and wind speed.

The frequency of the measurements for each system was: 15 minutes for district heating network, 5 minutes for electricity analyser, 5 minutes for parameters of IEQ and of external weather

ICT PSP Smart Build office building

The second case study is part of a project focusing on the application of ICT to suggest improved control strategies in several public buildings (i.e., offices, hospital, schools) located in Italy, Greece and Slovenia to save energy, reduce peaks and improved comfort conditions. This can be achieved via an integrated monitoring and control system which can keep track of the energy flows in the building, find out possible faults and suggest system improvements.

One of the analysed cases is a building with offices and a laboratory in Athens, Greece (CRES building) [8]. The building has been designed according to bioclimatic practices in 2001. The annual energy demand in degree days is 947 for the heating period (using 26°C as base temperature) and 5534 for the cooling period (using 20°C as base temperature). The single-story 300 m^2 building has a low consumption thank to on one hand an electrical heat pump that generates the thermal energy for heating and cooling and, on the other hand, a photovoltaic area of 300 m^2 (24 kW) that largely guarantees the electrical energy demand.

The following flow charts (Figure 4 and Figure 5) show the thermal and electrical plants of the building:

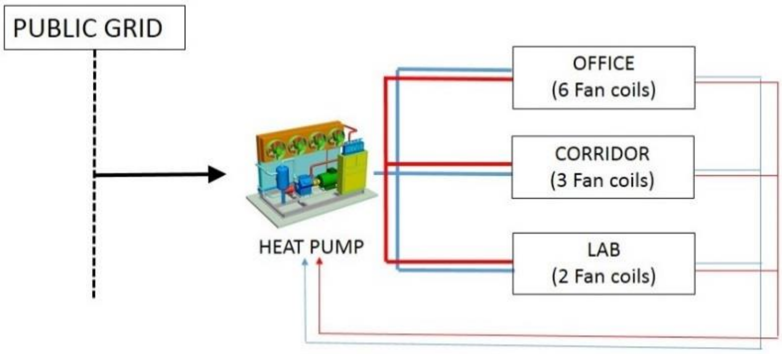

Figure 4. Thermal system flow chart of the CRES building

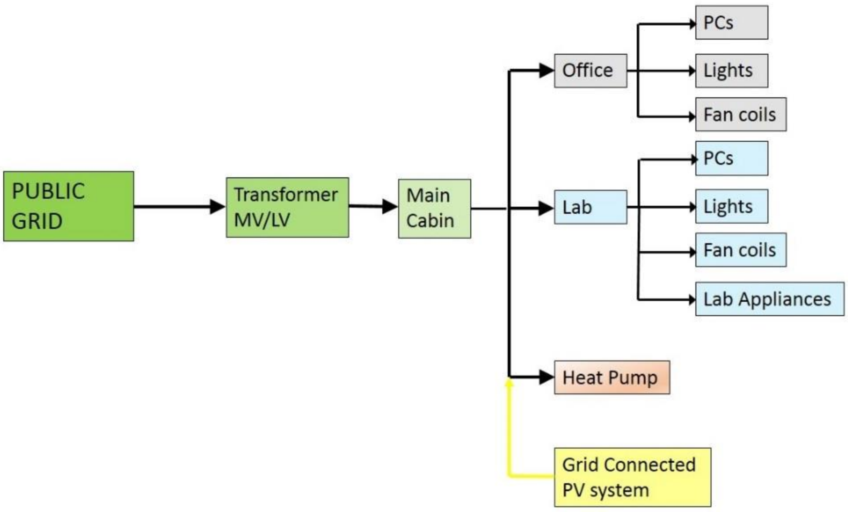

Figure 5. Electrical system flow chart of the CRES building

The monitoring system at CRES focuses on building energy demand and comfort as follows:

- Energy and power of whole building and of the heat pump
- Temperature, humidity, CO_2, presence and luminous intensity in 3 areas (2 offices and 1 laboratory)
- Temperature, humidity, wind speed and wind direction in a weather station

4 Results and discussion

SEE-Miniambiente "CasaNova" apartments

According to the general methodology described above, the in this case we utilized scatter, carpet, box plot and time series plot for the data analysis as they provide clear characteristic patterns. In the 'CasaNova' project, we analysed the data from October 2011 to April 2013. The results concerning the heating and domestic hot water (DHW) consumptions of the "Castle EA2"are shown in Figure 6 and Figure 7.

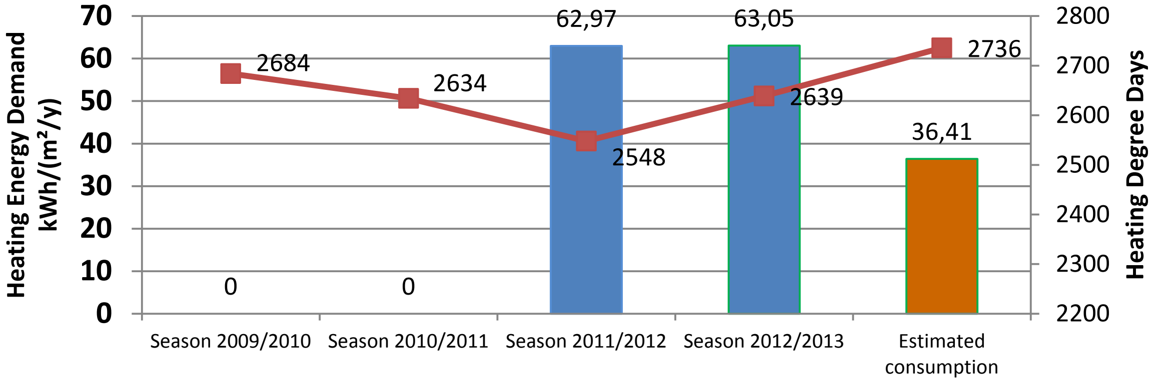

Figure 6. Castle EA2 – Heating consumption during season 2011/2012 and 2012/2013

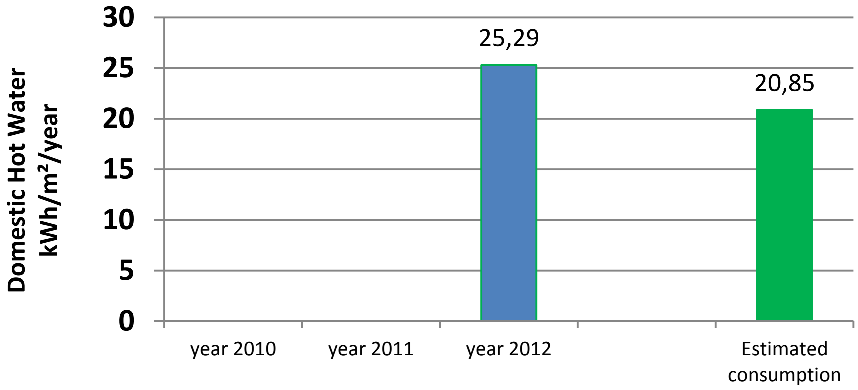

Figure 7. Castle EA2 – DHW consumption during year 2012

The graphs compare the estimated and the measured consumptions of the building. It can be seen that while the DHW consumption is very close to the real consumption (Figure 7), the heating consumption in the last two seasons is almost twice the calculated design consumption (Figure 6). The causes of this discrepancy is still under review but the tenant behaviour is likely part of the reason. The residents have an elevated influence on the heating consumption since they control the indoor temperature setting as well as the window opening. Increased indoor temperatures were observed as shown in Figure 8. This figure depicts how the indoor temperature in the apartment is greater than the design temperature (19-21°C) for most of the time; additionally, it reached peaks of 25-26°C. Moreover, the tenants also tend to open the windows while the heating system is operating as can be observed in Figure 9.

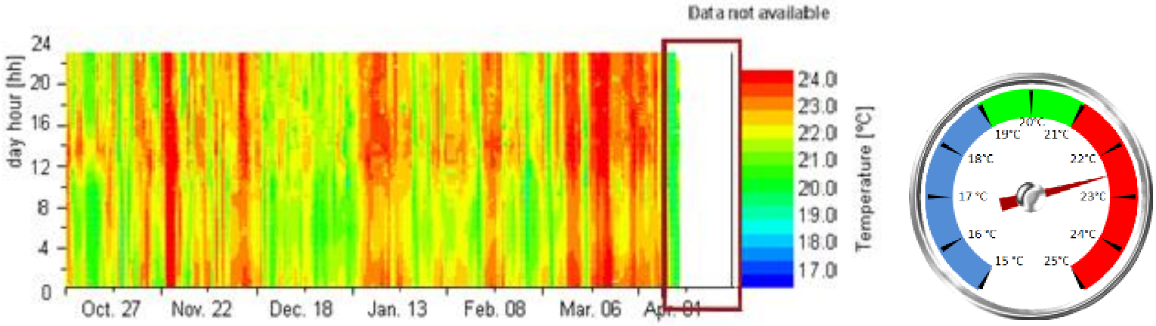

Figure 8. Temperature profile and meter indicator with average seasonal temperature of the apartment on the top floor during the heating season.

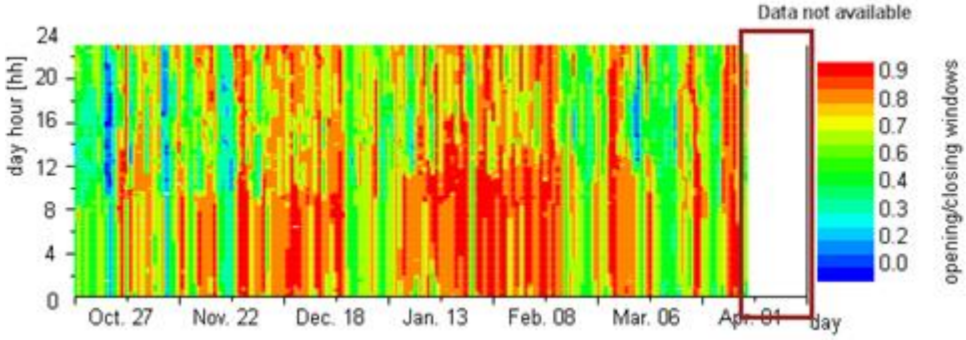

Figure 9. Opening/Closing windows in the apartment on the top floor during heating season. (1 closed – 0 Opened)

The same incorrect behaviour has been observed during the cooling season (Figure 11). The temperature of the flat exceeds the design temperature (26°C) for more than 50% of the analysed hours (see Figure 10).

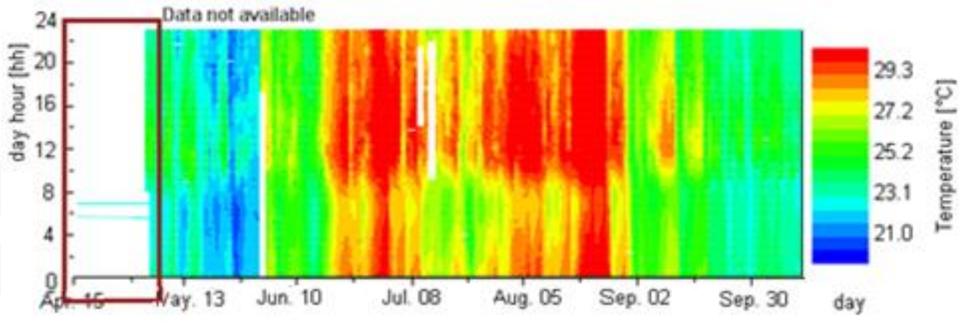

Figure 10. Temperature profile of apartment on the top floor during not heating season

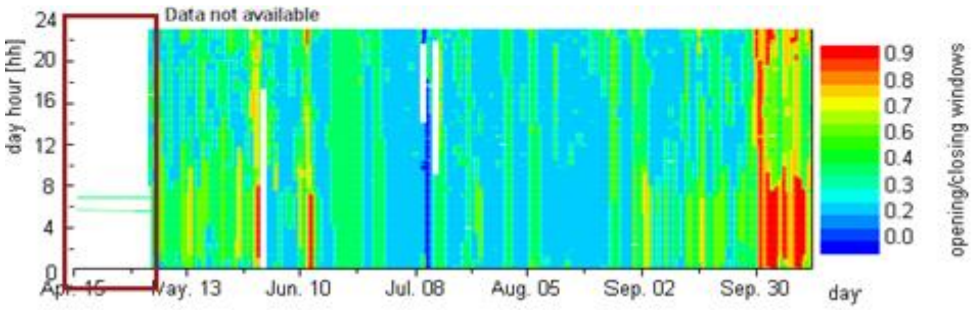

Figure 11. Opening/Closing windows in the apartment on the top floor during not heating season. (1 closed – 0 Opened)

The hygrothermal comfort falls into the ASHRAE comfort zones for the most of hours. However, it would be beneficial to achieve this result without the substantial waste of energy as mentioned before. Another fundamental aspect that has been analysed is the CO_2 concentration. As can be seen in Figure 12 for the apartment 1 on the ground floor, the concentration of CO_2 is higher than in the others, reaching peaks of 3400 ppm. After a brief survey, the problem has been located in the apartment's occupation and tenant's behaviour. The apartment covers an area of 80 m^2 and it is inhabited by 14 people, which are used to keep the windows closed for most of the time and some of them smoke inside. All that produces an exhausted air that could generate health problems, especially for children.

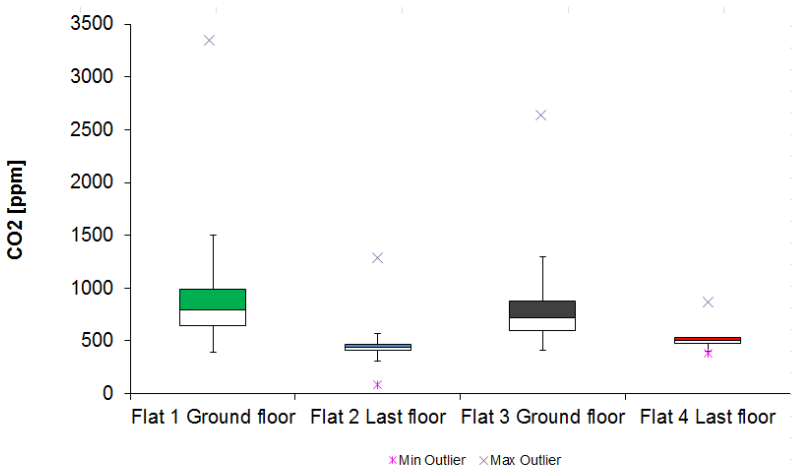

Figure 12. CO2 concentration in the apartments monitored

The next step of the project deals with the development of an energy report to share with the inhabits of the neighborhood, building owners and energy managers in order to show the results of the monitoring period and to identify solutions capable to reach greater energy saving (such as the training course for tenants and the maintenance of systems). Moreover, we want to underline the importance of continuous commissioning especially on building project and energy certification agency.

ICT PSP Smart Build office building

In the second case study considered, part of the Smart Build project, the analysis focused on the operation of the heat pump system and the achievement of a desired indoor environmental quality. The main aspects investigated are the electricity consumption of the heat pump, lights, appliances, the electricity production of the photovoltaic system, the internal comfort and the user behaviour. Figure 13 presents the breakdown of the overall electricity consumption for March 2013.

System	Month Average [kWh\m2]
Heating Pump	0.07
Light+appliances	0.08
UPS	0.02
Photovoltaic Plant	0.19

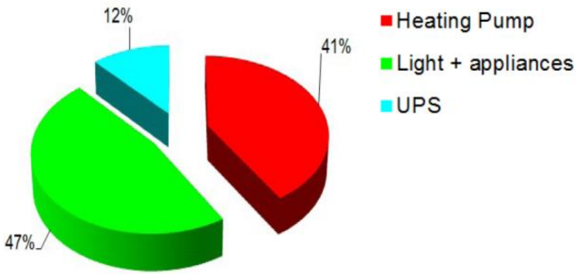

Figure 13. Electricity consumption of the building in March 2013. The UPS or battery/flywheel backup, is an Electrical apparatus that provides emergency power when the input power source, typically main power, fails.

According to the diagram in Figure 13, the electricity consumption is due to the heat pump for almost 40%, and the remaining 60% is due to lights, appliances and UPS system all together. A deeper investigation is still in progress, but the first results and the graph in figure 14 and figure 15 show that there is no correlation between the consumption of the electrical heat pump and the outdoor temperature. We even observed heating consumption for outdoor mean temperature of 23°C. Additionally, sometime the consumption is higher when the external temperature reaches average daily values of 22-23°C than when there are 17°C. Moreover, it starts during the night only for brief periods (see Figure 15). This behaviour denotes a typical problem of the regulation system, which influences the electrical consumption and the thermal comfort as well. A heat pump operation connected to the external weather should be able to reduce heating demand significantly. As can be seen in Figure 16, there are often cold conditions observed in the monitored offices (approximately 60% of the working days, considering only the working hours).

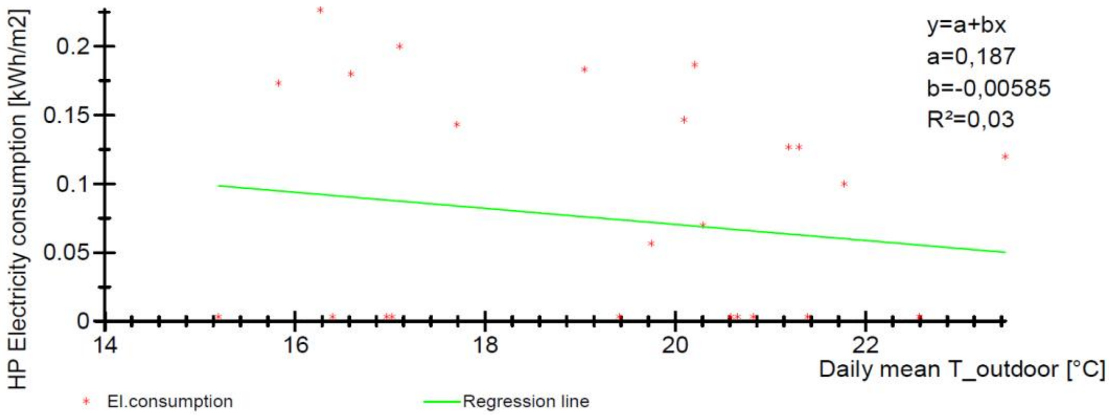

Figure 14. Energy signature of the building in March 2013

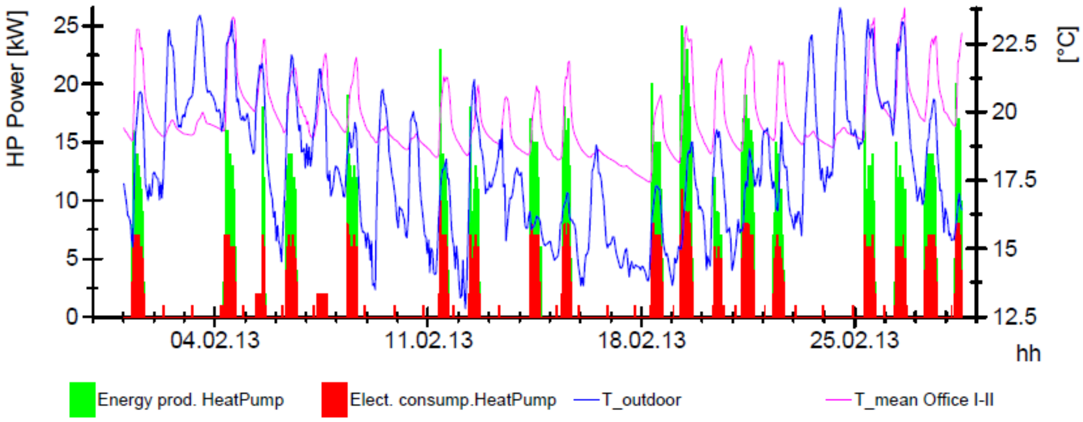

Figure 15. Correlation between Energy Production and consumption of heat pump and Temp. Indoor and Outdoor

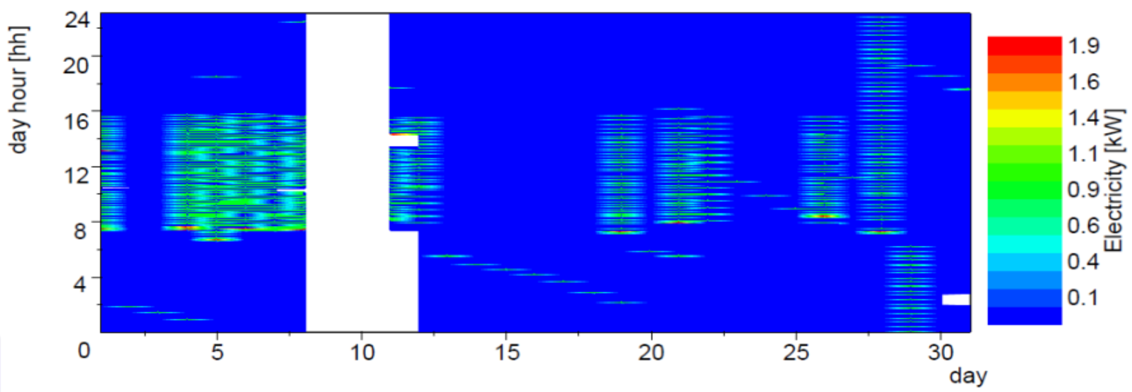

Figure 16. Electricity consumption of the heat pump during March 2013

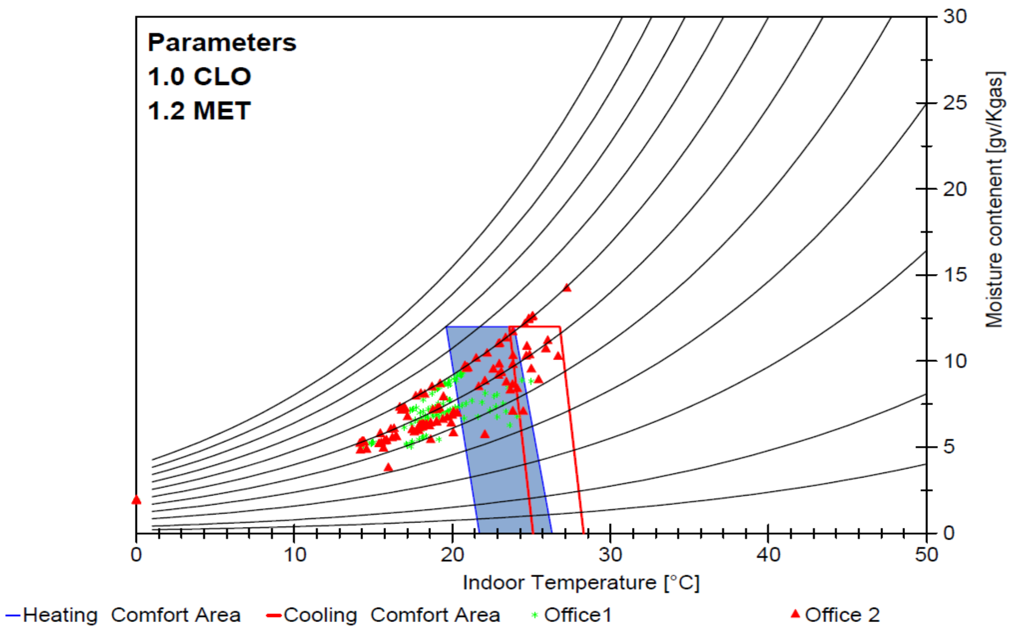

Figure 17. Daily ambient air temperature and humidity with ASHRAE comfort zones, considering only the working hours.

The next step of the project is the training of energy managers and occupant to educate them about correct operation and behaviour. Following the current analysis improved control strategies to apply to this building are being identified in order to reduce energy consumption, shift peaks, optimize photovoltaic production and improve occupant comfort. The solutions include the introduction of an automatic control in the heat as a function of the building occupancy and of the outdoor temperature as well the control of the sky-light windows to regulate indoor temperature and take advantage of night cooling. The aim of these measures is to reduce the energy consumption of more than 25%.

5 Conclusions

The continuous commissioning represents an excellent strategy to improve energy behaviour and the overall performance of a building. It requires the identification of the energy flows and parameters to monitor. Once the data is acquired, it needs to be processed to identify faults, incorrect settings and potential for improvement. The processing of great amount of monitoring data is a complex process needed to be able to make visualize the performance. In the current paper we identify a procedure assisted by a series of standard visualization tool and specific KPI that allows us to first identify potential problems for each analysed cases and, subsequently, to figure out the possible improvements to apply in the buildings. In the case studies presented we were able to identify anomalies and underline the importance of apartment user behaviours (e.g., temperature setting, window opening) and of the system control (heat pump regulation based on external temperature).

One of the main objectives is to develop energy reports and guidelines that could advice the tenants, the owners or the energy managers on the potential/possible actions to be implemented to solve the problems and improve the building/system performances.

Acknowledgments

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3. Validation Methodology for a Self-Learning Building Energy Management System

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Abstract

A novel general validation methodology has been developed in the SEEDS project and applied in two real cases with energy conservation measures from the ICT. The methodology identifies the most significant variables and develops statistical correlations between them and the building energy consumption in order to predict the hypothetical consumption if ECMs – Energy Conservation Measurements - were not applied.

The methodology includes the following stages:

- Collection of information about location and building features such as envelope, distribution, energy supply and demand. After that the measurement and verification plan is developed.
- The baseline and reporting periods are characterised using bills of energy suppliers and building monitored data. This information helps to take into consideration equations in order to foreseen building behaviour based on dynamic variables, mainly HDD, CDD and Solar Irradiation. Energy consumption equations are obtained and after that some routine adjustments, such as the occupancy schedule, are foreseen to correct them.
- These equations allow us to compare the results obtained during the reporting period with the results that would have been during this period if ECM had not been applied.
- The information generated will be:
    - Observed data of the reporting period: the measurement period start and end points in time, the energy data, and the values of the independent variables.
    - Description and justification for any corrections made to observed data.
    - All details of any baseline non-routine adjustment performed. Details should include an explanation of the change in conditions since the baseline period; all observed facts and assumptions, and the engineering calculations leading to the adjustment.

Finally a data analysis procedure has been developed in order to detect and understand the effects obtained by the Energy Conservations Measurements. Final results are not included because the reporting period has not yet been performed.

1 Introduction

The SEEDS project focuses on harnessing advances in self-learning methods, wireless sensor technology and building technology to develop a novel Self Learning Energy Efficient builDings and open Spaces (SEEDS) control system.

It aims to develop an energy management system that will allow buildings to continuously learn to maintain user comfort whilst minimising energy consumption and CO_2 emissions. SEEDS will develop an open architecture suitable both for retrofitting existing buildings and open spaces and design of new buildings. Buildings are considered to represent over 35% of energy consumption in the EU. Hence, SEEDS' capacity to continuously optimise energy consumption is due to the use of self-learning algorithms taking into consideration the particular characteristics of buildings. SEEDS has the potential to make a significant contribution to the EU's objective to reduce energy consumption and emissions.

SEEDS is based on research and scientific advances in wireless sensor technology, machine learning, and Bayesian networks, as well as standard statistical methods to enable the relationships between key variables to be continuously learned, facilitate prediction and a more efficient control. Research from the field of meta-heuristic methods will be utilised for optimisation of an objective variable, subjected to constraints that reflect requirements. Moreover their implementation in the Energy Management System is a progress beyond the state of the art.

Once the SEEDS' technologies have been implemented and adjusted in two case studies, an assessment of the reduction of energy consumption and CO_2 emissions need to be performed. The results will be compared to those that the pilot had before the implementation of the SEEDS' technologies, with suitable adjustment equations.

In both case studies, and during baseline and reporting period, appropriate equipment to measure and register consumption of external energy supplies (electricity and natural gas) has been installed. These energy meters are calibrated trough monthly consumption data provided by utility companies.

The paper shows a general procedure particularized to two specific buildings, where baseline energy consumption is calculated from two or three climatic variables and occupancy schedule is treated as a static factor.

The work starts with a description of the buildings and their energy systems, being followed by the description of energy conservation measures to be applied. Once the measurement extent is defined, a general methodology is applied and specific equations for two building demonstrators are obtained. Energy savings are estimated by comparing consumptions in reporting and baseline periods, with the corresponding adjustment equations.

2 Development methodology

The methodology developed in this paper follows the next scheme:

- Description of building, energy consumers and energy sources.
- Description of Energy Conservation Measures (ECMs) to be applied.
- Definition of energy system where savings are calculated and measurement boundaries. Location of energy meters.
- Baseline and reporting period data: identification of time period, characterization variables and static factors.
- Basis equations for adjustment.
- Procedure for data analysis and saving computation.

3 Description of building and energy systems

3.1 Demonstrator 1: Educational building in Stavanger (Norway)

The first demonstration building used to validate SEEDS methodology features next characteristics:

- Building E of a Stavanger University complex, with 5 floors and 15.362 m^2 (Figure 1).
- Type of use: auditoriums, classrooms, laboratories and offices.
- Lighting: on/off lighting system with movement sensors.

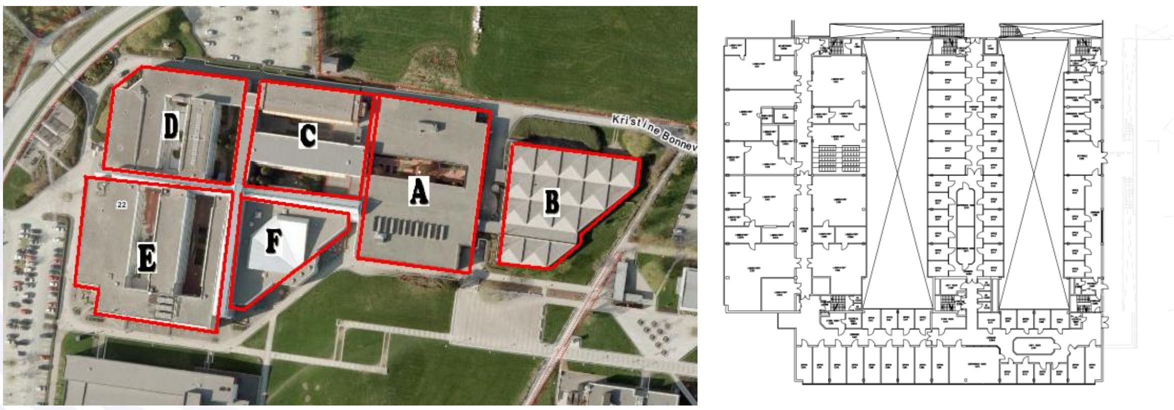

Figure 1: Location and plant distribution scheme of Demonstrator 1.
Source: University of Stavanger. SEEDS Project Partner

Energy sources:

- The only energy source is electricity, with two power transformers: T1 and T2

Thermal energy system:

The thermal energy system, outlined in Figure 2, consists of the following main items:

- Thermal energy producers for the building are:
  - 3 water cooled chillers producing both heating and cooling
  - 1 electric boiler and 2 DHW electric heaters
  - Individual electric heating for each room
- Thermal energy consumers are:
  - 4 Air Handling Units, providing heating and cooling, with volumetric flow control
  - 9 fan coils, which only provide cooling
  - 2 district rings with waterborne heating and cooling
  - DHW consumption

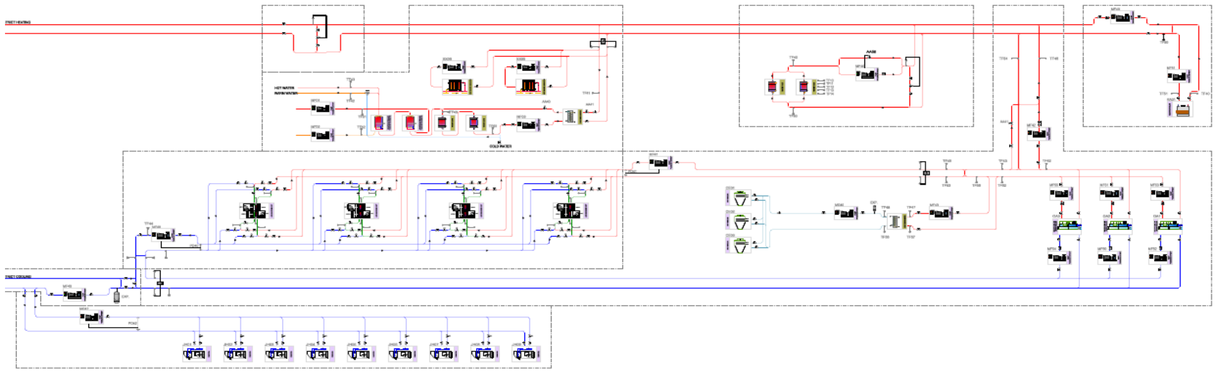

Figure 2: Connections between thermal system elements in Demonstrator 1. Source: CEMOSA and University of Stavanger. SEEDS Project Partners.

3.2 Demonstrator 2: Office Building in Madrid (Spain)

The demonstration building in Madrid features next characteristics:

- Building with six floors for offices use, with 4276 m^2 (see Figure 3).
- Ground floor for commercial use (600 m^2).
- Three underground floors for parking vehicles.

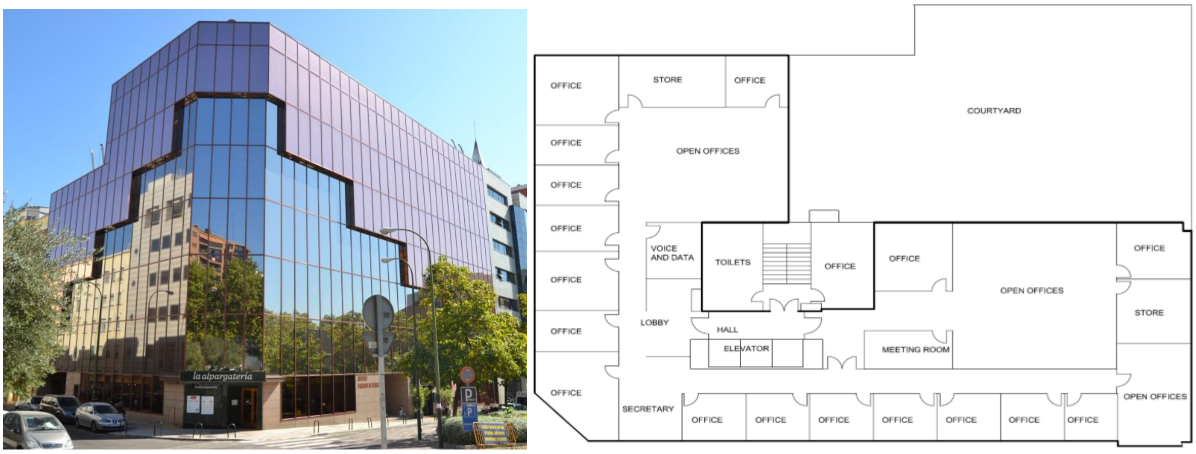

Figure 3: Location and plant distribution scheme of Demonstrator 2.
Source: FERROVIAL AGROMAN. SEEDS Project Partner.

Energy sources:

- Electricity, one power transformer with different energy meters:
    - HVAC system and other general services
    - Lighting and general consumption for floors 1 to 6 (out of the boundaries)
    - Underground floors (out of the boundaries)
- Natural gas, powering a boiler.

Energy systems:

- **Heating system:** Air to water heat pump + Gas boiler.
- **Cooling system:** Heat pump + 2 Air cooled chillers.
- **Air distribution:** 6 independent Air Handling Units with volumetric flow controllers. Possibility of "Free cooling". Three-way valves for hot and cold water.
- **Floor distribution system:** About 15 volumetric flow controllers per floor, actuated by temperature sensors
- **Domestic Hot Water:** 6 independent Electric Heaters.
- **Parking Air Exhaust:** 1 Fan per floor, fixed speed, actuated by CO sensors.
- **Lighting and electric plugs:** Independent for each floor (supported by the tenant).
- Lighting and electric plug outputs in common areas.

A scheme of thermal system is shown in Figure 4.

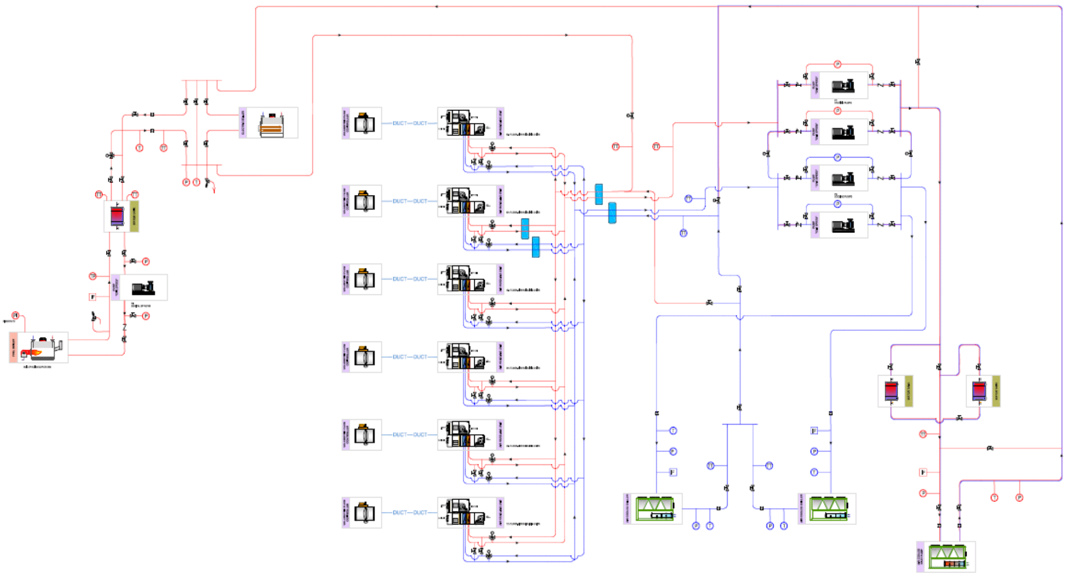

Figure 4: Connections between thermal system elements in Demonstrator 2. Source: FERROVIAL AGROMÁN and CEMOSA. SEEDS Project Partners.

4 Description of Energy Conservation Measures

Energy Conservation Measures (ECM) applied in both buildings are only related to the Building Energy Management System (BEMS), which are:

Wireless sensors:

Wireless sensors are distributed in all controlled rooms and in all energy system elements which need to be controlled. As can be seen in Figure 5, they consist of a series of sensor elements (temperature, humidity, lighting, air quality, presence, electric power or solar irradiation) a Printed Circuit Board (PCB) and an antenna in order to get wireless communication to the control system. All of them are inside a plastic box and powered with electricity. They have all the sensors for each element grouped together in a unique element, thus allowing a better and cheaper control, which is connected to the control system through gateway elements installed in each floor.

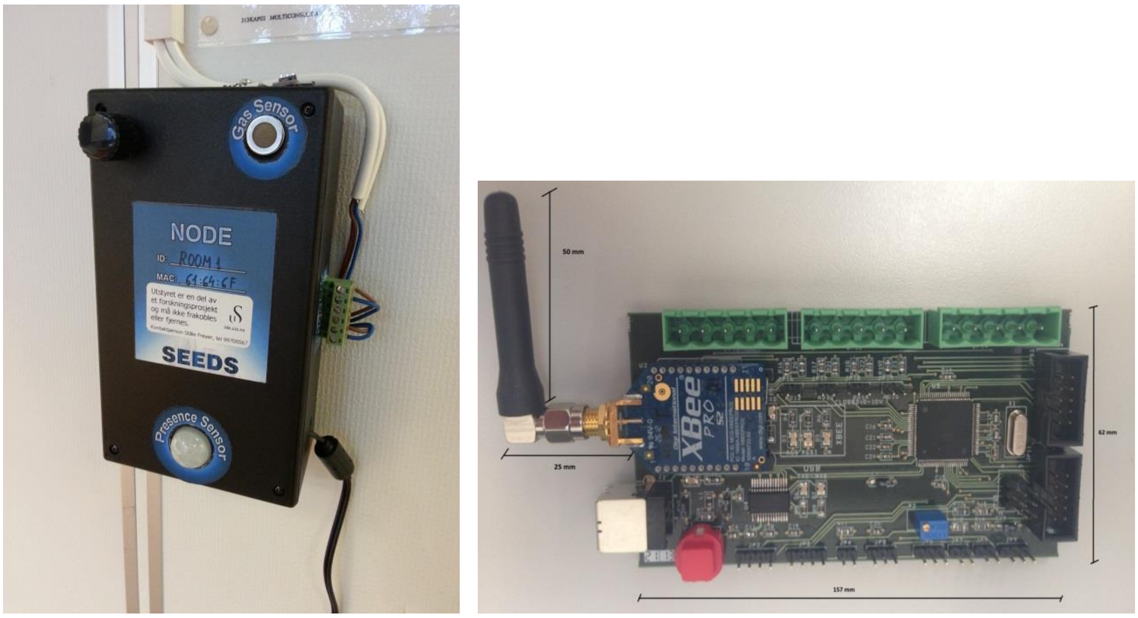

Figure 5: Room wireless sensor.
Source: SOFTCRIS. SEEDS Project Partner

__*Self-learning and optimization software:*__ Based on measured data, climatic predictions, building characterization data, and stored data from previous building performance, this module uses some Hard Disk Drives (HDD) and defines the action for the different system components. Its operating scheme is outlined in Figure 6.

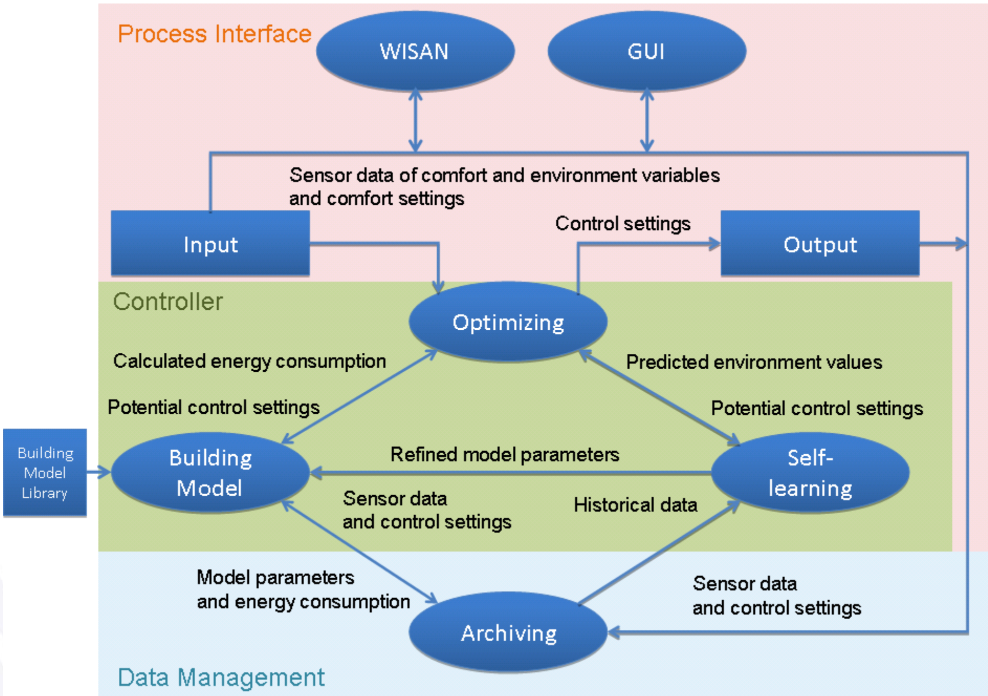

Figure 6: Scheme of core of SEEDS BEM system.

5 Measurement boundaries and energy meters.

5.1 Demonstrator 1: Educational building in Stavanger (Norway)

In this case, and with the purpose of validate the efficiency of SEEDS system, total building electric energy consumption is measured. In both baseline and reporting period monthly energy consumption is obtained as the addition of energy meters installed after transformers T1 and T2.

5.2 Demonstrator 2: Office Building in Madrid (Spain)

In the case of Madrid Building, is only being considered the energy consumed by the HVAC system. Lighting and other energy consumers are supported by the renter and the owner is not able to centralize or control this energy consumption. Parking underground floors have also been excluded because of the low consumption and low scope for improvement.

An electricity meter is installed in the HVAC electric line, while a volumetric energy meter is installed in the Natural Gas line. Monthly data are grouped together en both cases.

6 Baseline and reporting periods: Conditions, independent variables and static factors.

6.1 Baseline and reporting periods.

In Demonstrator 1, a regular period of one and a half year has been established as baseline period (from May-2011 to October-2012). During this period, energy consumption has shown a very good correlation coefficient with respect to independent variables.

In Demonstrator 2, a period of two years has been chosen (from December-2010 to November-2012). A period of a month was eliminated because of irregular behaviour (from January to February-2012). Correlation is fairly good for electricity, but not as good for natural gas because of changes in occupancy rate. This static factor shall be properly considered.

One year reporting period is planned for both demonstrators: starting in October 2013, it will run until the end of the project (September 2014).

6.2 Comfort conditions.

Comfort conditions, such as temperature, humidity, lighting level and CO_2 content in the inside air are measured in some rooms in both demonstrators during baseline and reporting periods.

6.3 Characterization variables and static factors.

As the energy savings are calculated in a monthly basis, only climatic variables will be reported. These variables will be the monthly cumulative HDD, CDD and Solar Irradiance.

HDD: Heating degree days (base 17ºC). Obtained by addition of daily differences between 17ºC and mean outdoor temperature ($\Sigma(17\text{-}t_{mean})$, whenever this term is positive.

CDD: Cooling degree days (base 17ºC). Obtained by addition of daily differences between mean outdoor temperature and 17ºC ($\Sigma(t_{mean}\text{-}17)$, whenever this term is positive.

Solar irradiance (SI): Monthly solar radiation (beam + diffuse) on horizontal surface (kWh/m^2)

While equations for Demonstrator 2 are using the three variables, Demonstrator 1 uses only HDD and SI, because CDD is really low in Norway.

Building indoor temperature is seen as a static factor, because SEEDS system is intended to have similar indoor temperatures in both reporting and baseline period. It will be measured and significant changes will be properly reported. Additionally, any changes that may occur in other static factors such as occupancy levels, building facilities or building characteristics will be properly reported and considered.

7 Basis equations for adjustment

7.1 Demonstrator 1: Educational building in Stavanger (Norway)

Two estimators have been tested in order to predict the building energy consumption. The first one considers only one variable while the second, with much higher accuracy, considers two variables (HDD and SI):

Estimator 1 = 300.7 + 0.4624*HDD   (R^2=0.90)

Estimator 2 = 359.3 + 0.3453*HDD – 10.73*SI   (R^2=0.97)

Month:	HDD	Solar irrad.	T1+T2	Estim:	Dif^2:
may-11	197	5.43	383.90	369.02	221.28
jun-11	122	5.58	335.18	341.52	40.26
jul-11	55	5.16	311.35	322.90	133.37
ago-11	62	4.09	341.56	336.80	22.67
sep-11	102	2.56	366.62	367.03	0.16
oct-11	198	1.26	419.34	414.12	27.22
nov-11	265	0.51	443.15	445.31	4.65
dic-11	386	0	483.48	492.56	82.34
ene-12	433	0.34	507.59	505.13	6.03
feb-12	424	1.05	489.97	494.41	19.71
mar-12	338	2.1	468.45	453.45	225.05
abr-12	335	3.74	417.99	434.81	282.99
may-12	232	5.43	398.79	381.11	312.63
jun-12	152	5.58	337.93	351.88	194.60
jul-12	82	5.16	324.64	332.22	57.36
ago-12	58	4.09	351.43	335.42	256.57
sep-12	156	2.56	374.60	385.67	122.62
oct-12	283	1.26	450.85	443.47	54.44
				SUM:	2063.96
				R^2:	0.968657952

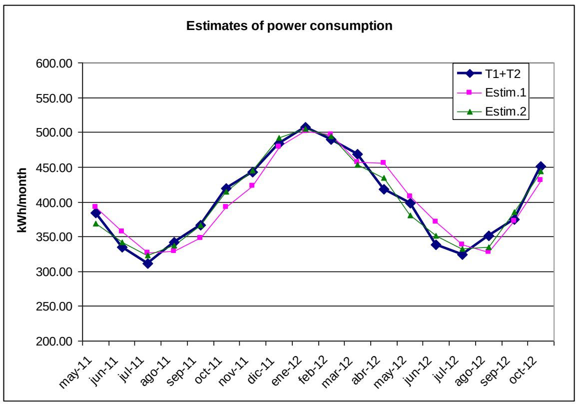

Figure 7: Analysis of estimators for building energy consumption in baseline period (Demonstrator 1). Source: CIDAUT. SEEDS Project Partner.

According to these calculations, the expression for power consumption, in kWh/month, expected in the building without the ECMs is:

Expected Power Consumption (EPC_{D1}) = 359.3 + 0.3453*HDD – 10.73*SI (Estimator 2)

7.2 Demonstrator 2: Office Building in Madrid (Spain)

In this case, Power consumption and Natural Gas consumption have to be separated into two different estimators (Figures 8 and 10). The first one covers the whole period and uses three variables (SI, HDD for heating period and CDD for cooling period). Estimator for Natural Gas consumption only covers heating period and uses two variables (SI and HDD).

Estimator for Power consumption:

Month:	Days:	TOTAL KWh	Daily	HDD	CDD	SI	Estimated	Sq. Dif:
DJ/10	35	8796	**251**	353	0	1.91	149	10558
JF/10	26	5482	**211**	316	0	2.59	117	8793
FM/10	29	3175	**109**	267	1	3.79	77	1051
MA/10	34	1579	**46**	170	22	4.80	99	2808
AM/10	28	5995	**214**	107	56	5.63	205	81
MJ/10	31	16247	**524**	47	122	6.65	455	4756
JJ/10	28	29491	**1053**	7	270	7.10	1097	1876
JA/10	33	40546	**1229**	1	299	6.59	1235	42
AS/10	30	30902	**1030**	12	189	5.30	761	72224
SO/10	32	9048	**283**	87	67	3.66	275	65
ND/10	29	1980	**68**	311	1	1.83	131	3961
JA/11	31	36325	**1172**	3	283	6.59	1161	126
AS/11	31	22495	**726**	12	213	5.30	867	19965
SO/11	30	13237	**441**	66	105	3.66	435	39
ON/11	31	1657	**53**	159	25	2.44	142	7842
ND/11	30	2158	**72**	301	1	1.83	123	2567
DJ/12	31	3433	**111**	374	0	1.91	161	2502
FM/12	28	4000	**143**	260	13	3.79	124	344
MA/12	29	2773	**96**	185	10	4.80	54	1751
AM/12	30	7714	**257**	97	87	5.63	342	7177
MJ/12	31	19779	**638**	23	209	6.65	835	38870
JJ/12	29	34428	**1187**	3	278	7.10	1130	3222
JA/12	35	43148	**1233**	1	311	6.59	1290	3275
AS/12	27	27332	**1012**	13	206	5.30	839	30053
SO/12	30	8801	**293**	77	80	3.66	325	986
ON/12	36	2976	**83**	178	15	2.44	108	619
							SUM:	**225553**
							R^2:	**0.95326818**

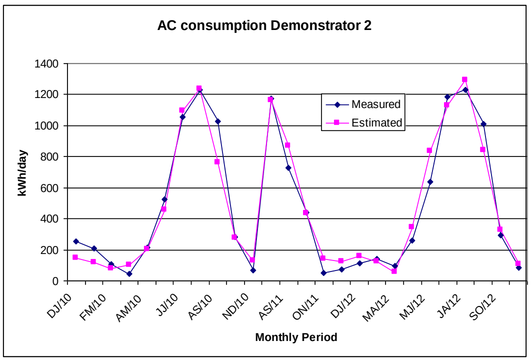

Figure 8: Analysis of estimator for Power consumption in baseline period (Demonstrator 2). Source: CIDAUT. SEEDS Project Partner.

According to these calculations, the expression for power consumption, in kWh/month, expected in the building without the ECMs is:

Expected Power Consumption (EPC_{D2})=-27.17+0.57795*HDD+4.5431*CDD-14.876*SI (R^2=0.95)

Natural Gas consumption:

In the case of Natural Gas Consumption, if the whole period is considered, the estimator features a really low correlation coefficient (Figure 9). This result comes as a consequence of the variation in building occupancy level (see Figure 12), which underestimates power consumption during the first year and overestimates it during the second year. A more precise estimator is intended to obtain, including data from year 2013 and taking into account a new variable related to building occupancy.

Whole period:

MONTH:	Days:	TOTAL KWh	Daily	HDD-17	SI	Estim:	Dif^2:
DJ/10	29	73782	2544	353	1.91	1479	1134628
JF/10	29	45835	1581	316	2.59	1326	64882
FM/10	27	45378	1681	267	3.79	1203	228181
MA/10	32	21614	675	170	4.80	572	10606
AM/10	29	2692	93	107	5.63	216	15295
ON/10	28	1080	39	210	2.44	284	60369
ND/10	32	17209	538	311	1.83	1057	269510
DJ/12	33	47257	1432	374	1.91	1677	60107
JF/12	29	33726	1163	369	2.59	1823	436087
FM/12	30	33986	1133	260	3.79	1134	2
MA/12	33	9307	282	185	4.80	716	188673
AM/12	29	10145	350	97	5.63	126	50209
ON/12	30	2668	89	178	2.44	-16	11038
						SUM:	2529585
						R^2:	0.64368

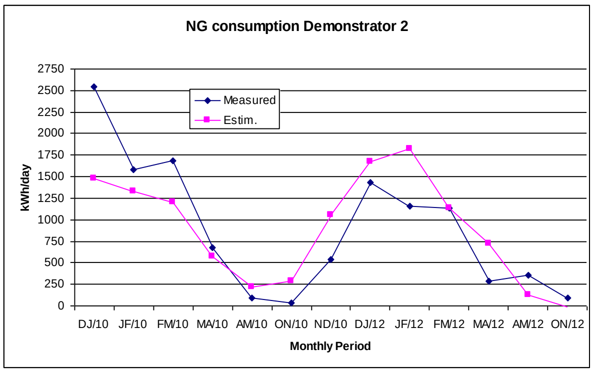

Figure 9: Analysis of Natural gas consumption in baseline period (Demonstrator 2, two years period). Source: CIDAUT. SEEDS Project Partner.

The equation in this case, with a low correlation, would be:

NGC=-2376.5 + 9.3875*HDD + 282.55*SI

Year 2012:

A better estimator is obtained by using only the year 2012 period (Figure 10).

MONTH:	Days:	TOTAL KWh	Daily	HDD-17	SI	Estim.	Dif^2:
DJ/12	33	47257	**1432**	374	1.91	1272	25554
JF/12	29	33726	**1163**	369	2.59	1355	36976
FM/12	30	33986	**1133**	260	3.79	883	62365
MA/12	33	9307	**282**	185	4.80	592	95891
AM/12	29	10145	**350**	97	5.63	191	25377
ON/12	30	2668	**89**	178	2.44	156	4480
						SUM:	250643
						R^2:	0.84315

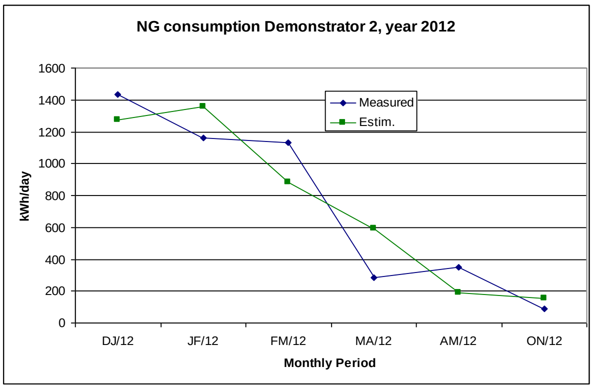

Figure 10: Analysis of estimator for Natural gas consumption in baseline period (Demonstrator 2, year 2012). Source: CIDAUT. SEEDS Project Partner.

According to these calculations, the expression for natural gas consumption, in kWh/month, expected in the building without the ECMs is:

Expected Natural Gas Consumption ($ENGC_{D2}$) =-1342.4 + 6.135*HDD + 166.5*SI (R^2=0.84)

<u>Explanation about the effect of Solar Irradiance:</u>

A positive dependency of natural gas consumption on solar irradiation may be a little puzzling. Why statistics say that? The answer is that solar irradiation and heating degree days are no independent variables. SI is affecting GN consumption in the direct way but it is also affecting in the indirect way through HDD. Which of them is higher?

HDD is a direct consequence of daily solar irradiation but also solar irradiation of precedent days and months (that's the explanation why, in the Northern Hemisphere, temperatures are much higher in September than in March, with similar solar irradiation levels). In a simpler model, and assuming a linear dependence of HDD on SI, a correlation factor may be obtained (Figure 11):

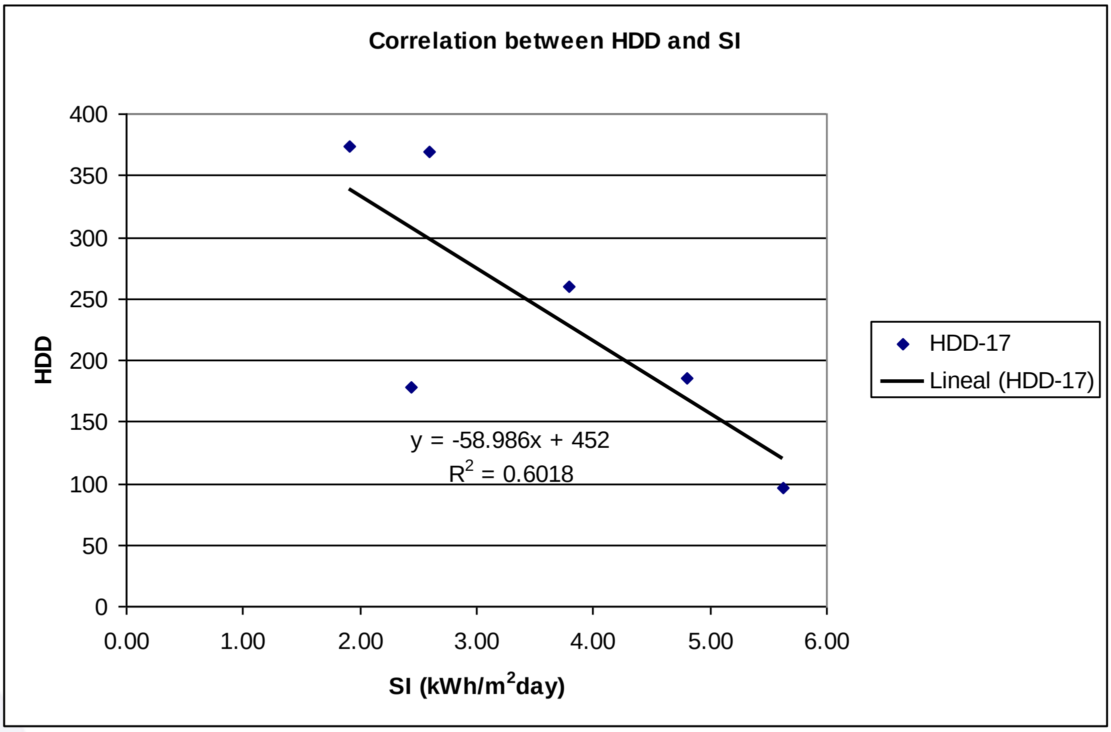

Figure 11: Correlation coefficients between HDD and SI (Demonstrator 2, year 2012). Source: CIDAUT. SEEDS Project Partner.

Considering this relationship, the effect of SI on GN may be roughly expressed as:

GN ≈ A + 6.135* (B-59*SI) + 166.5*SI ≈ C – 362*SI + 166.5*SI **≈ C – 195.5*SI**

So, this effect is clearly in the indirect way.

	P1_DCHA	P1_IZQ	P2_DCHA	P2_IZQ	P3_DCHA	P3_IZQ	P4_DCHA	P4_IZQ	P5_DCHA	P5_IZQ	P6_DCHA	P6_IZQ
nov-09	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
dic-09	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
ene-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
feb-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
mar-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
abr-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
may-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
jun-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
jul-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
ago-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
sep-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
oct-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
nov-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
dic-10	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
ene-11	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
feb-11	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
mar-11	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
abr-11	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
may-11	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
jun-11	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
jul-11	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
ago-11	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
sep-11	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
oct-11	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
nov-11	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
dic-11	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
ene-12	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
feb-12	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
mar-12	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
abr-12	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
may-12	X	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
jun-12	X	X	OCUPADO	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
jul-12	X	X	OCUPADO	X	OCUPADO	OCUPADO	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
ago-12	X	X	OCUPADO	X	OCUPADO	OCUPADO	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
sep-12	X	X	OCUPADO	X	OCUPADO	OCUPADO	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
oct-12	X	X	OCUPADO	X	OCUPADO	OCUPADO	X	OCUPADO	OCUPADO	OCUPADO	OCUPADO	OCUPADO
nov-12	X	X	OCUPADO	X	OCUPADO	OCUPADO	X	OCUPADO	OCUPADO	OCUPADO	X	X
dic-12	X	X	OCUPADO	X	OCUPADO	OCUPADO	X	OCUPADO	OCUPADO	OCUPADO	X	X

Figure 12: Occupancy schedule in Demonstrator 2 (period 2010 to 2012)

8 Procedure for data analysis and saving computation

8.1 General procedure

The procedure to collect and analyze data in a general case is shown below:

During baseline period

- Collect all monthly consumption data (electricity, natural gas and/or others) from utility suppliers. Monthly periods should be adjusted, as far as possible, to the reported period indicated in the bill.
- Collect all daily mean temperature data and solar irradiance from national weather agencies or other acknowledged entity. Obtain HDD, CDD and SI for every monthly period.
- Measure indoor temperature and humidity levels.
- Collect occupancy and/or other significant data.
- Obtain suitable and accurate estimators for every energy supply, using the method of minimum square differences.

During reporting period

- Collect all monthly consumption data (electricity, natural gas and/or others) from utility suppliers. Monthly periods should be adjusted, as far as possible, to the reported period indicated in the bill and to the reported periods taken during baseline.
- Collect all daily mean temperature data and solar irradiance from national weather agencies or other acknowledged entity. Obtain HDD, CDD and SI for every monthly period.
- Measure indoor temperature and humidity levels.
- Collect occupancy and/or other significant data.

After reporting period

- Calculate **monthly** fixed conditions **energy savings** according appropriate equations.

  If any static factor (indoor temperatures, occupancy or others) has changed significantly, appropriate non-routine adjustments must be defined and applied.
- Calculate **annual energy savings** as a sum of monthly savings.
- Evaluate the **CO_2 savings and**, if possible, **economic savings**.

8.2 Expressions for savings

For a correct evaluation of savings, estimated savings must be expressed as a function of measured energy consumption (MEC, MPC in the case of power or MNGC for natural gas) and expected energy consumption without ECMs (EEC, EPC or ENGC):

Estimated savings = Estimated energy consumption of precedent systems in reference period – Measured energy consumption in reference period

- ES = EEC – MEC

In the case of demonstrators 1 and 2, the expressions are:

Power energy saving demonstrator 1:

- $PES_{D1} = EPC_{D1} - MPC_{D1}$

Power energy saving demonstrator 2:

- $PES_{D2} = EPC_{D2} - MPC_{D2}$

Natural gas energy saving demonstrator 2:

- $NGES_{D2} = ENGC_{D2} - MNGC_{D2}$

Where expected consumptions are obtained from section 7.

9 Conclusions

A specific methodology has been developed in order to compare energy efficiency improvement due to energy conservation measures carried out over two case studies, one in Northern-Europe and the other in Southern-Europe.

Characterization variables and static factors affecting energy consumption have been identified and the equations taking into consideration its effect have been explained.

If changes in indoor temperature and occupancy are not expected, climatic variables will themselves result in an accurate prediction of monthly building performance.

Although these particular cases are focused on IC Technologies, the developed methodology is valid for all type of ECMs in buildings and open spaces.

Acknowledgments

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4. KPIs for S.M.A.R.T. Cities

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Abstract

Smart cities promise major contributions to achieving the EU 20/20/20 goals. With EC policy documents repeatedly underlining the energy and cost savings potential that public and residential buildings have, various solutions are being trialled in projects including FP7, CIP and IEE among others. This paper presents a framework for defining and implementing key performance indicators (KPIs) based on S.M.A.R.T. principles and provides examples for indicators fitting these principles. A brief guide and examples on how KPIs can be easily adopted by a large number of projects show a path towards widespread usage.

Index Terms — key performance indicator, KPI, energy efficiency in buildings, EeB, smart city, smart grid, smart meter, performance measurement, ontology, evaluation, S.M.A.R.T.

***Remark**: Sections requiring discussion at the workshop are introduced in boxes such as this one.*

1. Introduction

The EU has set the ambitious target of saving 20% CO_2, increasing the level of renewables to 20% and increasing energy efficiency by 20% by the year 2020 (20/20/20 goals; [2012/27/EU]). Reaching these milestones will require significant investment in our cities and buildings, in particular to exploit the potential of information and communication technologies [COM(2011) 109 final]: to make cities and grids [COM(2011) 202 final] smarter. For achieving these goals, each Member State has to translate these milestones into (revised) National Energy Efficiency Action Plans (NEEAP) [2010/31/EU].

Within this framework, EC policy rightly places the public and residential buildings sector centre stage, as one the largest areas for potential savings, causing 40% of total emissions [2013/105/EC]. Implementation of smart metering [2012/148/EU], if done properly, will enable consumers to take a much more active role in managing their consumption, by detecting patterns and by adapting their behaviour in order to reduce overall, as well as peak-time, consumption. Supported by EC contributions, various solutions to accomplish these targets are being developed and subjected to trial in projects under R&D and policy support programmes [2012/C 99 E/14] - FP7, CIP and IEE in particular.

Ensuring progress to promote energy efficiency is one issue in policy, while making use of pilot projects' outcomes to properly support decision making by stakeholders, is another. Both require clear, appropriate and comparable metrics of performance. Currently, projects have a range of different approaches to performance reporting; some projects have no well-defined indicators and, generally, indicators are not measured to the same standard across projects. Consequently, tracking progress and comparing achievements on energy savings and improved energy efficiency becomes difficult, if at all possible, leaving stakeholders and decision makers without the necessary information to make good choices for investment.

This paper seeks to establish a framework for designing and providing key performance indicators (KPI) to public and other stakeholders involved in implementation of smart cities projects. This framework covers various issues to be applied during the projects' design phase, such as: audience, scope, categories, principles and units. It also includes considerations regarding selection, assessment and implementation of KPIs by different stakeholders. In addition, various examples of KPIs compliant with the framework are given, together with an preliminary implementation guide for involved stakeholders.

Chapter 2 briefly introduces the concept of KPIs as well as definitions and sources used for the collection presented in chapter 3, followed by a short guide for application in individual projects in chapter 4.

2. Framework for EeB KPIs

This chapter describes the framework in which the KPIs have been developed and the terminology used in this paper. The aim is to establish a language with as few items as possible while establishing criteria allowing KPIs to be defined for as many environments as possible. This is also in line with research action to establish a common vocabulary or glossary to be supported using semantic web standards. Therefore terms proposed for agreed inclusion in a limited common vocabulary and to establish a glossary are shown in bold print.

2.1. Definition

Key performance indicators (KPIs) are performance metrics explicitly linked to a strategic objective that help translate strategy execution into quantifiable terms. KPIs provide visibility of the performance of a business or project and enable decision makers to take action to ensure or accelerate achievement of the desired outcomes.

Application of KPIs to business enterprises is standard management practice. Application to policy monitoring in cities is a more complex undertaking. This is because of policy complexity in particular, but also because of the problem of attribution in an environment of multiple actors affecting policy outcome.

In most cities, a variety of complex policy actions are underway attempting to make progress along multiple dimensions of policy, some belonging to the notion of smart city, some not, or not directly, e.g. employment, but of no less importance. Whether a measure has had the desired impact or whether the impact was achieved "by accident" – a reduction in traffic through the city, a warm winter etc. – is sometimes an important issue, referred to here as the **attribution** problem.

Our approach to KPI definition attempts to take account of the complexity of policy objectives and the proposed application of KPIs takes account of attribution problems.

2.2. Audience

The main audience for this paper are public bodies introducing innovations in the building sector, aiming to increase resource efficiency, who require an improved approach to assessing the success of their policies. A key group are local and city councils[4] and social housing companies, who control an important segment of the residential building sector[5]. Moreover, publicly funded research projects, whether initiated by universities, other public research organisations or private enterprise, are also expected to welcome use of a common set of KPIs, as these are a necessary basis for comparison of findings.

Organisations wishing to monitor progress and compare outcomes by applying KPIs are **stakeholders** in energy saving, and multiple organisations in the same project may be stakeholders in this sense. Since the applicability of KPIs is not limited to public bodies, a stakeholder may also be a private organisation implementing energy efficiency measures (e.g. energy management in an office block). The responsible individual applying KPIs and / or keeping track of success and documentation will be referred to as a **user**. This is independent of the hierarchy and means by which the KPIs are being managed. Examples given in this paper mostly deal with users in stakeholder organisations which are city councils.

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[4] See, for instance, SmartSpaces (4)

[5] See, for instance, eSESH (2) or BECA (3)

2.3. Scope

The paper focuses on **projects** comprising one or more **measures** aiming to increase resource efficiency, or other targets linked on the path towards smart cities, applied to **structures** (e.g. building, room or other built space).

In principle, the KPI developed here are such that a stakeholder can measure a KPI for each measure and structure individually. This will, however, not usually be appropriate, as variation in outcome often cannot be assessed at the level of an individual structure. To properly attribute changes in KPI to the measures which were intended to change them, comparison between sets of structures is necessary. It is therefore generally recommended to cluster structures and control the number of measures applied in one project. This enables the stakeholder to properly identify and interpret the success of a measure, excluding by statistical techniques the possible effect of a large number of exogenous variables.

Which measures are to be tracked with KPIs must be defined ex ante if ex post attribution of success to measures is intended. Decisions on continuation or expansion of a measure will often be based on results using KPIs (see links 1, 4 and 5). Transparency is increased by communicating which method and data will be used. Ideally, the responsible staff are able to calculate the KPIs by themselves and track their progress in order to ensure that considerations about future actions and possible improvements do not start with discussions on whether the KPI is useful or calculated correctly.

2.4. Categories

In the field of resource conservation and energy saving, as elsewhere, KPIs are aligned to (policy) objectives which are multidimensional in character. The dimensions of policy objectives will normally be reflected in classification of the KPIs, each addressing a specific dimension of policy. At a more practical level, KPIs can be allocated to domains to support the organisation of data collection - setting measurement targets and assigning responsibilities to the relevant departments. Overall, three categories are proposed to cluster key performance indicators:

- **Environmental**: KPIs relating to one or more 20/20/20 or associated goal.
- **Economical**: KPIs to assess the financial impact of any given measure.
- **Service-level**: KPIs to expose the quality of a service or measure provided and / or adding welfare or utility to society, not covered by the categories above.

All stakeholders are likely to wish to use the first two categories '**environmental'** and '**economical'** (ALwaer& Clements-Croome 2010). For some policy contexts and project measures, performance at **'service-level'** will also be relevant, as here the domain includes indicators of impact on social issues.

2.5. Principles

The S.M.A.R.T. approach (Doran 1981) was applied to establishing environmental KPIs - resource saving and resource efficiency KPIs. This approach reduces the risk of KPIs being redundant for staff or a department (Kerzner 2013). Furthermore, it enables the stakeholder to give a clear direction and objectives to the user (or department) in achieving the goal(s). The S.M.A.R.T approach is defined as follows:

- **S**pecific: What?, Who?, Where?, Which?
- **M**easurable: Unit?, Granularity?
- **A**ttainable: Realistic?, How?
- **R**elevant: Why?, Strategic fit?
- **T**ime-bound: When?, How long?

This paper outlines KPIs primarily using the first two principles (specific and measureable), by defining what is being assessed and which units are to be used. The remaining principles (attainable, relevant and time-bound) are taken into account as constraints but are recommended to be explicitly defined by the stakeholder implementing the project in question.

2.6. Units

In order to compare the impact of measures across structures, projects or cities, the units need to be clearly defined and appropriate.

For each indicator, a selection of units is provided with which the KPI can be measured and assessed. Typically these are an absolute change, a percentage change, or a change in relation to some scale metric, such as number of people affected or size of structure (room, building) affected. Use of relational units implies the ability to generalise impact measured in a small number of structures to a large number, e.g. dividing a gross saving achieved by a measure in a pilot project by the number of square metres of building space in that project to then extrapolate what the impact would have been, or will be, at city level.

2.7. Selection

The selection of KPIs is guided by fit to (policy) objective, feasibility of measurement and affordability of measurement. As the installation of metering and sensors to measure KPIs is not an end in itself, the criterion of measurement *affordability* reflects an economic argument: the improvement in decision quality expected from use of the KPIs, and the expected payoff from that improvement, compared to the cost of use of the KPI in question.

Another criterion which may be used in selection is to assess whether a KPI and its units can easily be used in public communication e.g. via (local) media, and whether it is likely to be easily grasped and not cause misunderstanding among the wider public.

2.8. Assessment and implementation

However clearly a KPI may be defined, the values obtained may in some cases depend on the detail of the methodology by which measurement is made, or on the way missing data compensated for, or on how spurious variation in values is dealt with. For such KPIs, particularly if measurement is not performed by the same personal across all projects within a city, it is recommended to agree upon the methodology with which performance is being assessed and data prepared. Software supporting data capture can avoid problems here as well as mistakes e.g. in the units to be applied.

2.9. Limitations by design

The number of KPIs defined in a monitoring framework depends on the complexity of objectives to be tracked. In addition, the timing and frequency of measurement is an issue, e.g. whether a KPI is measured on a daily basis, more or less frequently and whether progress is assessed regularly, on a monthly or yearly basis, or for a one-off decision. The former choice depends on the overall approach to variability of outcome over time; the second depends on the use the KPI-based assessment is to be put to.

2.10. Modelling exogenous variables

When the impact of a measure (e.g. consumer support) on policy objectives (e.g. energy saving) is to be tracked using KPIs, it is often the case that the impact (energy consumption) depends on factors other than the measure. In the field of building energy, use of the building is of course a key factor, along with weather variables. A KPI which is so affected cannot really be interpreted without compensating for these exogenous factors. This is not a simple issue in many cases. For example, a simple occupancy variable may not be appropriate. Some individuals may have control over variables influencing the consumption of a given structure while others do not. Compared to visitors, staff working in public buildings usually both have some control and remain for longer periods within a building.

3. KPIs for EeB towards smart cities

This chapter introduces key performance indicators supporting realisation of smart cities, grouped by the categories introduced in section 2.4. The tables presented in this chapter do not contain a complete framework as the focus is on common KPI. Further detail – see section 4.1 – requires knowledge of context of application: project, structure and (policy) measure. The proposed referencing is documented in the Annex (see 7.1).

3.1. Key performance indicators

3.1.1. Sources for indicators

The KPIs listed below follow existing European recommendations or collections of key performance indicators along with experiences collected in EU-funded projects. Key sources are among others the '*Commission recommendation on preparations for the roll-out of smart metering systems'* [2012/148/EU] and the 'Guidelines for conducting a cost-benefit analysis of Smart Grid projects' (JRC 2012) (partly based on the results of the EC Task Force for Smart Grids.

Further contributions came from the consortium Ready4SmartCities and experience from numerous projects on energy efficiency using ICT were taken into account. The list cannot be regarded as final, but must be modified in line with policy changes and changes in availability and/or cost-effectiveness of new measurement systems.

3.1.2. Environmental KPIs

Ref*	KPI**	Unit***
I.1.a	Electricity Saving	per cent
I.1.b		kWh (MWh)
I.1.c		kWh/m²
I.1.d		kWh/person
	Electricity Production	per cent
		kWh (MWh)
	Electricity Production	per cent
	Capacity	MW
	Electricity Peak Demand	per cent
	Reduction	kWh (MWh)
	Electricity Peak	per cent
	Response Capacity	kWh (MWh)
	Heating Saving	per cent
		kWh (MWh)
		kWh/m²
		kWh/person

	Heating - District	per cent
	Heating	kWh (MWh)
	Hot Water Saving	per cent
		m³
		m³/person
	Hot Water Production	per cent
	(Solar Thermal)	m³
	Cold Water Saving	per cent
		m³
		m³/person
	Grey Water reused	per cent
		m³
	CO_2 Saving	per cent
		metric tons
		kg/m²
		kg/person
	NO_x Reduction	per cent
		metric tons
		kg/m²
		kg/person
	SO_2 Reduction	per cent
		metric tons
		kg/m²
		kg/person

* ***Ref*** *- Reference of a single indicator which can remain unchanged even if the KPI is being translated in other languages.*
*** **KPI** short name*
**** **Unit** listing a complete list of all available units for any given KPI following the framework outlined in chapter 2.*

3.1.3. Economic KPIs

Given the complexity and variance in energy efficiency installations, any detailed list of, for instance, operational cost is unlikely to be all-embracing: Total operational cost is the sum of various items for which calculation (and data source) of individual items might differ. The results, however, are expressed using the same unit. Hence, the list of economic KPIs is kept deliberately short to ensure that the audience can make use of the KPIs without adjustments or conversion.

Ref	KPI	Unit
II.1.a	Net Benefit	Currency
II.1.b		Currency/m²
	Economic Return	per cent (ratio)
	Socio Economic Return*	per cent (ratio)
	Return on Investment	Years
	Implementation Cost	per cent
		Currency
		Currency/m²
		Currency/person
	Resource Cost Reduction	per cent
		Currency
		Currency/m²
		Currency/person
	Operation Cost Reduction	per cent
		Currency
		Currency/m²
		Currency/person
	Reduced Oil Usage	Currency
		litres

3.1.4. Service-level KPIs

Ref	KPI	Unit
III.1.a	Reduced outages	minutes
III.1.b		number (of incidents)
	Reduced wide-scale blackouts	minutes
		number (of incidents)
	Reduction in Energy Poverty	Currency
		persons
		kWh
	Time to connect a new user	days

	Users with access to regular web-service	customers per cent
	Users with access to peak response service	customers per cent
	Response time to malfunctions	days
	Response time to user feedback	days
	Active inclusion of citizens*	persons
	Access to the internet	households per cent
	Coverage by public Wi-Fi hot spots	km² per cent
	Average internet speed	Mbit

** Referring to disabled or social benefit receivers taking on roles such as energy coaches or similar.*

4. Guide to Implementing Smart City KPIs

Defining KPIs is not sufficient if neither processes to evaluate the targets nor methodologies needed to assess performance are in place. This chapter addresses these issues and proposes a structure for a template for public use.

4.1. Structure for KPI documentation

This section divides the KPI documentation required in two parts. Firstly, the 'project' specifies the purpose of KPIs and secondly the sections.

4.1.1. Project definition

The definition of the project clearly specifies what is being assessed with the KPIs selected. It defines "where from" data will be needed and "what" is to be assessed by the KPIs. Defining structures and measures once allows quick matching of these towards KPIs. Some KPI might not be relevant for a given measure (or structure) collected in the same project.

- The entire project:
  - Title
  - Stakeholder – usually the funding or organising party selecting KPIs
  - User – responsible individual(s) for tracking and assessing KPIs

    - Total cost
- For each structure:
    - Title
    - Location - address
    - Surface area - m²
    - Staff - persons having control over environmental variables
    - Visitor - persons without control; less likely to be regularly in the structure
    - Other projects in the same structure and any effect it might have on this project
- For each measure:
    - Title
    - Materials to be purchased
    - Equipment affected
    - Description

4.1.2. KPI definition, assessment and documentation

This section describes additional information required for all KPIs, as outlined in chapter 3, without implying that all KPIs are equally relevant for all stakeholders.

The outline below describes central steps users would need to perform. The letters in brackets indicate the S.M.A.R.T. principle(s) to be covered by the given item (see section 2.5).

Key performance indicators (as defined by the document)

The user selects applicable, feasible and affordable indicators from the list. Once the filters have been applied, only those KPIs remain for which targets are to be set at the next step.

- Reference
- KPI-definition (S,A)
- Unit (S,M,R)

Definition of targets

The user sets targets for each individual KPI deemed applicable.

- Goal – the overreaching policy goal (R)
- Period – by which the KPI should be assessed (S, T)
- Target – figure against which success will be determined (S,A)
- Date – point in time by which KPI should be achieved (T)

Assessment

The user provides information necessary for the assessment as such (and for future repetition) while recoding the approach, procedure and details leading to any given result.

- Data sources required (M)
- Granularity required (M, A)
- Method used, if applicable link to tool (S, A)

- Date of assessment (T)
- Result of assessment
- Notes

Example

The outline assumes KPIs will be applied to entire projects. Software based documentation could additionally assist in tracing back individual items to structures (and measures). This can simplify the overall assessment where data comes from individual structures (e.g. consumption information). On the other hand, additional effort would be needed to map each KPI against each applicable structure and measure taken.

Ref	KPI	Unit	Period	Target	Date	Data	Granularity	Method	Date	Result
I.1.a	Electricity Saving	per cent	year	11%	17.01.14	E-metering	Daily	eeMeasure		
I.1.c		kWh/m²	month	4	30.06.13	E-metering	Daily	eeMeasure	05.07.13	4,3
I.1.d		kWh/person	month	40	30.06.13	E-metering	Daily	eeMeasure+division	05.07.13	32

4.2. Provision to Cities

The implementation path for policy makers is presented in two stages. The first stage focuses on distribution and usage of KPIs, while the second one provides users also with the necessary tools to assess the performance and to transparent documentation.

A common format can help reduce the effort required to measure the success of projects and ensure comparability. This can be achieved by providing a formalised template following the structure suggested above. In a first step, the user outlines the project (e.g. location, involved individuals). Secondly, the user excludes all KPIs (and units) not applicable or relevant for the project in question. In a third step, the user adds missing details such as the overreaching goal and the date by which the KPI should be achieved. Additional columns ensure traceability and documentation.

Given appropriate online tools to support the steps described, cities would be able to manage KPIs for numerous projects at a time, also allowing multiple user access. An online platform could provide the hosting organisation with statistical data on which KPIs and units are most commonly used across Europe providing insight on which figures to use in public communication. This tool, for instance, could be hosted on the *Smart Cities and Communities* (5) platform. Comparability will be almost fully achieved once different projects use the same methodology for attributing outcomes –KPIs – to the measures taken.

To increase transparency, selected KPIs could be hosted together with city-wide policy (goals) on the council web-site. The data could also be made available for download as part of an 'open data' strategy. Moreover, online tools could be deployed for "crowd sourcing" of KPI data. Citizens could be enabled to contribute measures to specific KPIs and also document their achievements. For instance, a council might define a KPI for installation of renewable energy production by means of photovoltaic: After setting-up an account, citizens would document the capacity installed and the energy produced – in cases where this information is not already directly available from the utility.

The implementation of the *eeMeasure* tool for calculating resource savings in social housing and public buildings is also a useful example on designing a common format of reports based results using the same methodology across various European projects.

4.3. Implementation Examples

Empirica has recently been working on two tools which might be helpful in this context. The tools are being used in European projects.

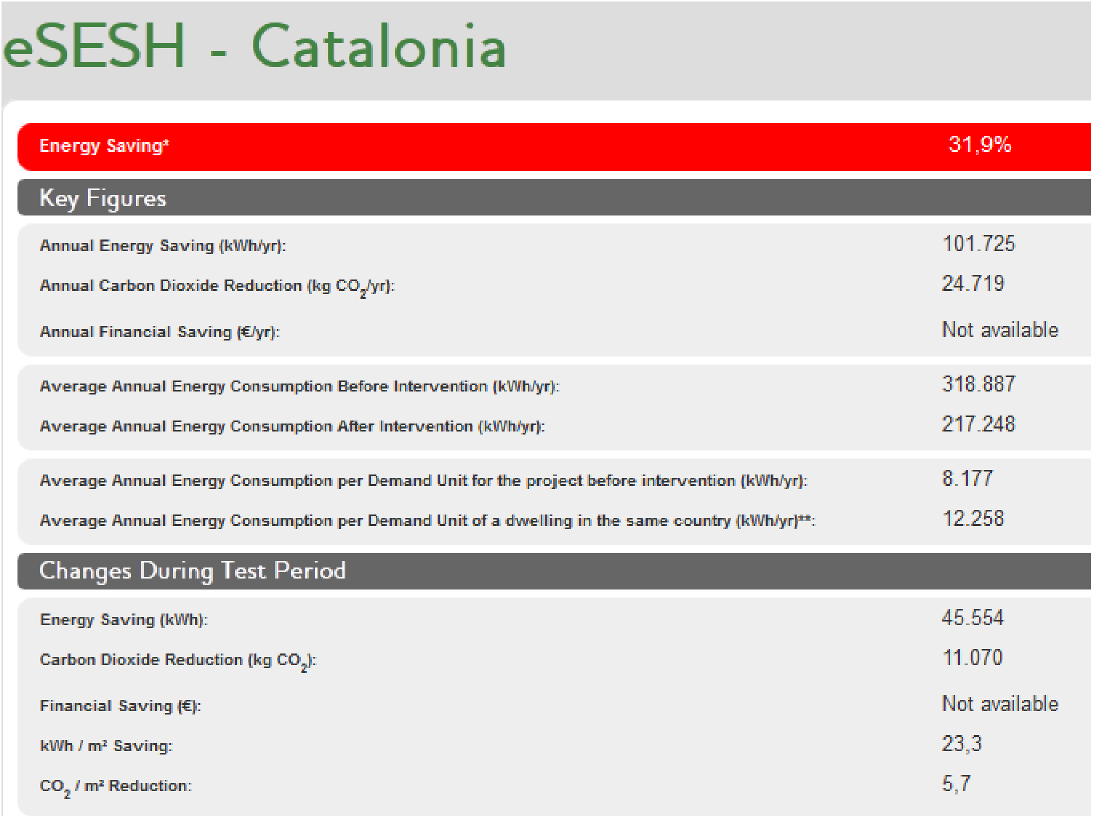
4.3.1. The eeMeasure tool

This section describes an example, focusing on environmental KPIs, in which numerous elements of the framework presented, have been implemented for European projects funded by the EC. Currently, the tool is being used by social housing companies and will be used by city councils to measure their success in achieving the outlined resource saving targets.

The EC commissioned the web-based tool '*eeMeasure*' to enable ICT PSP projects to compare the achievement of their innovative measures using a standard, rigorous methodology which fully addresses the attribution problem. The tool enables projects to upload data points not only for the time after a measure or "intervention" has been implemented, but also data points for a comparable set of buildings, using before-after (baseline comparison) or control group designs. The tool uses a consistent methodology which enables the European Commission and other interested parties to generate clear statistically validated analysis of the energy savings achieved by ICT based solutions in residential and non-residential buildings.

The key performance indicators covered on project level in *eeMeasure* are:

- Energy (kWh)
    - Total Saving per year (kWh/yr)
    - Saving per surface (kWh/m²)
    - Total Energy consumption per demand unit (kWh/m²)
- CO_2 equivalent emissions (CO_2)
    - Total saving per year (t CO_2/yr)
    - Saving per surface (kg CO_2/m²)
- Financial savings (€)



eSESH - Catalonia

Energy Saving*	31,9%
Key Figures	
Annual Energy Saving (kWh/yr):	101.725
Annual Carbon Dioxide Reduction (kg CO_2/yr):	24.719
Annual Financial Saving (€/yr):	Not available
Average Annual Energy Consumption Before Intervention (kWh/yr):	318.887
Average Annual Energy Consumption After Intervention (kWh/yr):	217.248
Average Annual Energy Consumption per Demand Unit for the project before intervention (kWh/yr):	8.177
Average Annual Energy Consumption per Demand Unit of a dwelling in the same country (kWh/yr)**:	12.258
Changes During Test Period	
Energy Saving (kWh):	45.554
Carbon Dioxide Reduction (kg CO_2):	11.070
Financial Saving (€):	Not available
kWh / m² Saving:	23,3
CO_2 / m² Reduction:	5,7

Figure 1 - eeMeasure tool: summary for a pilot site in Catalonia as part of the eSESH project ("Saving Energy in Social Housing with ICT")

Furthermore, statistical information is provided such as comparison with the average consumption in the same country. Each result is coded with climate zone, property type, energy sources and types as well as the interventions used.

4.3.2. Cost-benefit analysis tool

This section describes an example, focusing on economics KPIs, in which numerous elements of the framework presented have been implemented for European projects funded by the EC. The tool is being used by social housing companies and will be used by city councils to measure success in achieving outlined economical targets.

The Cost-Benefit-Analysis Tool (CBA) is being used jointly by all stakeholders of the same pilot site in the projects eSESH and BECA (and will be used in SMARTSPACES). The Excel tool enables sites to enter key information about the current solution ('do nothing' scenario) and cost items of the new (smart) solution. The tool allows multiple stakeholders and incremental spreading of each cost item (and resulting benefits) in the main categories implementation, operation and consumption. As the underlying calculations are equal across all sites, partners are not only able to model different scenarios for their pilot but also compare certain indicators between pilots

The figures below depict screenshots of key results for a selected site.

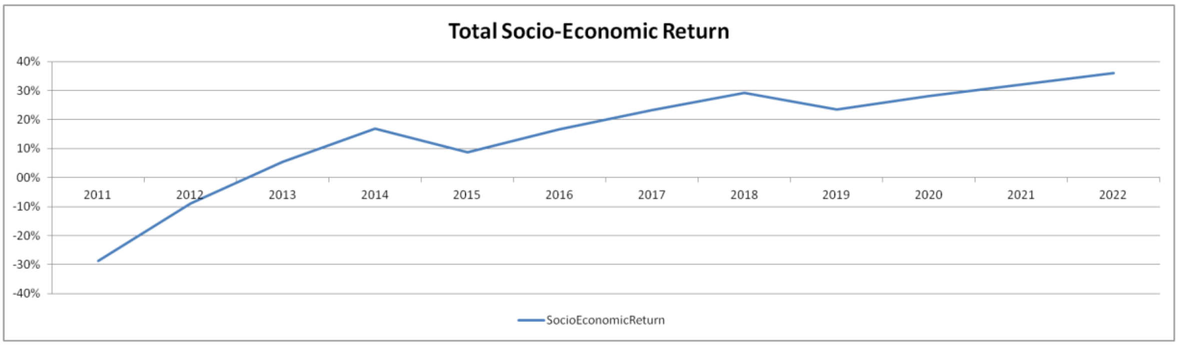


Figure 2 – CBA: Total Socio-Economic Return for entire site (example)

Cumulative net benefit	2.313	€
Cummulative socio-economic return	44,20%	
Return on investment	44,20%	
ROI in years	8,68	years

Cumulative Changes in Costs and Benefits caused by BECA (Graph)

Select values to be used: Cash Flow Changes - Net Present Value corrected

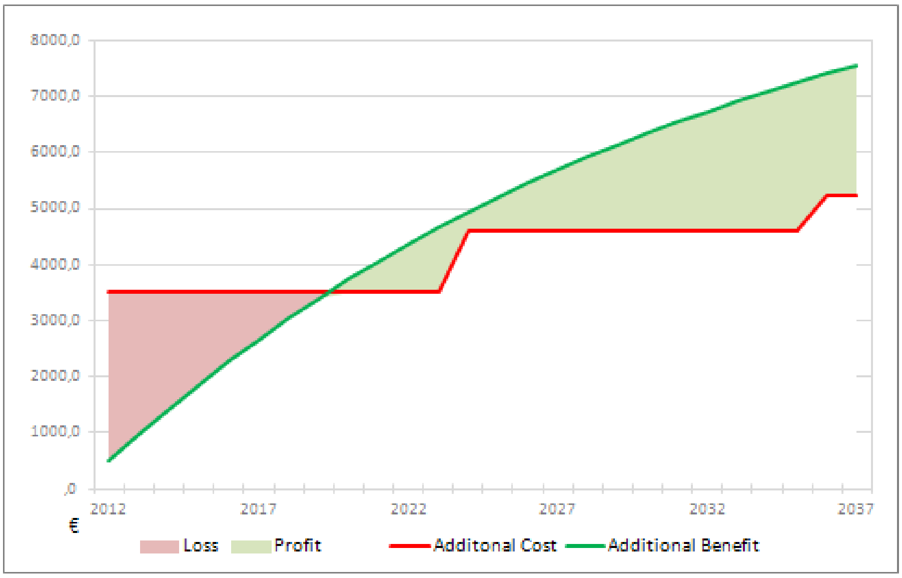


Figure 3 - CBA: Stakeholder specific result (example)

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Annex

Referencing pattern (proposal)

This section proposes a referencing pattern of splitting KPIs into groups, following the categories defined above and counting KPIs within these groups. Should any KPI be measured with more than unit, each unit is referred to with a letter, also allowing for future potential extensions. Indicators can be added at the bottom of groups, as can additional units for the indicators.

Examples of references and the corresponding KPIs are:

I.3.a	Environmental – Electricity Production Capacity – MW
II.2.b	Economic – Net Benefit – Currency/m²

Groups

Each group is referred to with a Roman numeral:

- I – Environmental
- II – Economic
- III – Service

Key performance indicators

Each indicator is referred to with an Arabic numeral starting from 'one' within each group, for instance:

- 1 – Electricity Saving
- 2 – Electricity Production
- 3 – Electricity Production Capacity

Units

Each unit is referred to with a small Latin letter starting from 'a' within each indicator, for instance:

- a – per cent
- b – kWh (MWh)
- c – kWh/m²

Additional instances created by the user

The user might want to create multiple versions of the same indicator, for instance, to cover 'resource cost reductions' for different resources.

The instance is an addition to the regular reference starting with an underscore ('_') followed by an Arabic numeral starting from 'one' within each unit only added if the number of instances is greater than one, for instance:

- I.3.a_1
- I.3.a_2

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